SuperWay

A Solar Powered Automated Transportation System

San José State University

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Abstract

The SuperWay is a solar-powered Automated Transit Network (ATN) system designed for urban and suburban areas, such as the Silicon Valley. The system is designed to provide an alternative to both the personal automobile and public transportation. The ATN system costs lest to construct and to maintain than existing mass transit approaches, reduces wait and travel times, and uses existing transit corridors. More land-use conscious and 100% solar powered, this ATN design is sustainable where existing transit solutions are not.

The design challenge was divided in to six engineering components of cabin, propulsion, structure and guideway, solar energy, control systems, and station design and two non-engineering concerns: urban planning and business case. Each component was analyzed separately in order to determine the best design. The design process included four stages: researching the state-of-the-art in each functional area, developing functional specifications and constraints, selecting the optimal technology in each functional area; and lastly, designing a prototype system. The route and urban planning were also considered, which included corridor selection, land use entitlements, and environmental impact assessment.

The research and calculations determined that the passenger cabin should fit four adults and have approximate interior dimensions of 80 in. length x 52 in. width x 69 in. height. The propulsion method to be used is a linear induction motor (LIM) that is capable of achieving a cruising speed of 50 miles per hour. The cabin is to be suspended from the guideway with a ground clearance of at least 14 feet. The columns that support the guideway are to be made of A574 grade 50 steel and spaced 40-50 ft. apart. The guideway is to be a Pratt truss. Stations are to include angled-berth tracks, with options for sub-lines for higher traffic areas. Solar panels to be used are "Sunpower SPR-440NE-WHT-D" modules at a 32 degree tilt and 190 degree azimuth. Control, schedule, and routing of the vehicles use a hybrid centralized system, which holds supervisory authority over semi-autonomous subsystems.

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Chapter 1: Executive Summary

Automobile transit in the United States of America is quickly becoming unsustainable as the population density increases. As a result, traffic congestion is causing commute times to reach unacceptable levels, driving up the already significant negative environmental impact caused by the inefficient combustion of fossil fuels. As implemented the alternatives to the automobile are unfortunately less than appealing.

The Sustainable Mobility System for Silicon Valley (SMSSV), a team of Business, Urban Planning, Software, Mechanical, Civil, and Computer Engineering students at San José State University (SJSU), has worked for the better part of eight months to specify the Superway, a fully functional automated transit network (ATN) for Silicon Valley based on personal rapid transit concepts. Significant interest in this system continues to be shown from the cities of Mountain View, San José, Sunnyvale, Milpitas, and several others in and around Silicon Valley.

The SMSSV team adopted several specific design criteria with the ultimate goal of creating a safe, sustainable, and efficient transit solution.

Given the obvious troubles with the dominant transit system, the Superway design is intended to minimize the environmental impact of moving people between the places where they live, work, play and shop. The design team decided on a suspended system to minimize the negative visual impact. This suspended design gracefully incorporates a solar cell umbrella over the rail system which is capable of providing nearly 100% of the Superway's energy needs. Using the best available transit supportive land use metrics, optimal system routing has been determined to minimize resource use and maximize potential ridership. To minimize the impact of constructing the system, much of the Superway design is modular, allowing individual pieces to be fabricated in one location and then quickly assembled at the construction site.

Cognizant of America Disability Act (ADA) guidelines, passenger safety was a critical concern throughout the design process. The design of the passenger cabin (or 'pod') provides a comfortable and safe environment for all passengers, regardless of their unique physical requirements. Inspired by cinema seating, the pod features folding seats allowing wheelchair access to all pods.

To be attractive as an alternative to the freedom provided by an automobile, the system must be convenient and time efficient. By design, all stations will be located off of the mainline of travel, allowing pods to bypass one another. This off-line station decreases travel time and improves customer service by minimizing the stops an individual must endure moving from place to place. The linear induction motor propelling the pod will be capable of a reasonable 50 miles per hour (MPH). Combined with the off-line station, this rate of travel should offer travel times lower than all other alternatives (including the automobile) in reasonably dense urban areas such as the Silicon Valley, especially during commute hours.

The control system uses a three-tier architecture featuring a Master Controller (MC) which monitors and oversees a large set of distributed semi-autonomous subsystems. The MC acts as the central authority for the entire system, monitoring the transit network's health and alerting each subsystem to potential trouble that the subsystem may encounter. With a system wide perspective, the MC can redirect idle pods to areas of the network where those pods can be most useful. Each pod contains an Autonomous Pod Control system which will safely move the pod between stations and provides a safe and comfortable ride. At potentially flow constricting merge points, a specialized Merge Controller coordinates traffic through the intersection by negotiating and allocating merge windows with the incoming pods. Finally, the control system will be complemented by a Reservation System which will allow passengers to purchase tickets through terminals and web accessible platforms and provide the MC with sufficient information to predict the optimal distribution of pods.

Chapter 2: Introduction

Motivation

Based around the automobile (a 19th century technology), transit in the United States of America (America) is quickly becoming unsustainable. Costs for building the necessary infrastructure for automobiles are outpacing inflation (Federal Highway Administration, 2012). Fuel costs are skyrocketing (Bureau of Labor Statistics, 2012). America is not building enough roads to keep up with the population (Federal Highway Administration, 2012). Commute times are increasing, and the current alternatives are not persuasive enough to serve the populace (U.S. Census Bureau, 2011).

Rising Road Way Costs

Over the past 50 years, the expenditures per mile of road have doubled the rate of inflation in America (Bureau of Labor Statistics, 2012). Interestingly, in real dollars, the expenditures per road-mile outpace the growth of the general economy for all two year periods, except for the 1980 – 1983 timeframe (an oversight Regan dramatically compensated for in 1985, allowing expenditures per road mile to climb by four times the prevailing rate of inflation in that year alone). As land values increase, especially land in urban areas, and obliterating the government's ability to find affordable surface level transit corridors, the trend will necessarily continue.

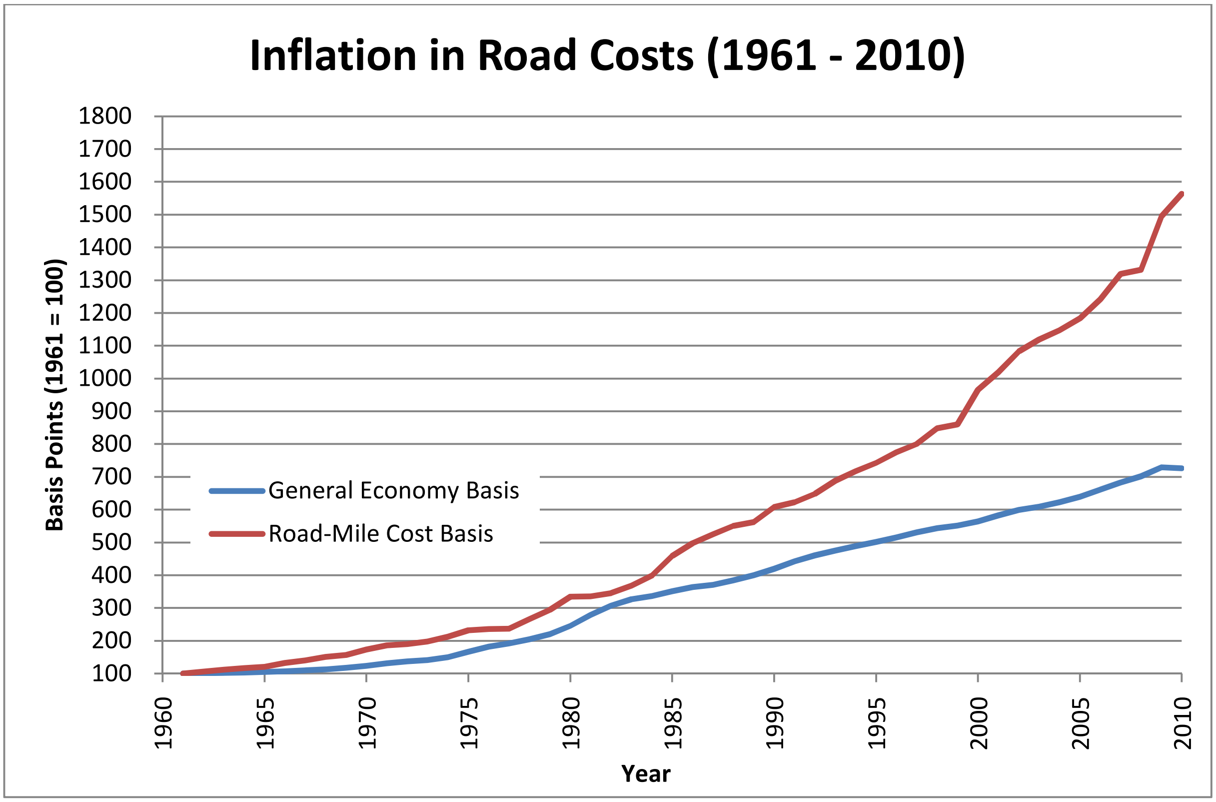


Figure 1: The cost to build roads has greatly outpaced the general inflation rate. (Bureau of Labor Statistics, 2012)

Roadway Availability

Since at least 1961, America has not invested sufficiently in roadways to keep up with the growth in the licensed driver population. Further, as the following figure demonstrates, each driver in 2010 is driving 16.6% further than they did in 1961 (Federal Highway Administration, 2012). The combination of fewer roads per person and more miles traveled necessarily indicates that any extra capacity built into America's roadway system will eventually be consumed. Since 1980, the average commute time has increased 20% (U.S. Census Bureau, 2011), indicating the exhaustion of excess capacity has already occurred for much of America. Though there is some curtailment of this trend due to the recession of 2008, the rapid recovery from the oil embargoes of the 1970's indicate resumption of increased need for travel will occur as the economy recovers. Fundamentally, despite spending an increasing amount in real dollars per road-mile, America cannot keep up with its growth.

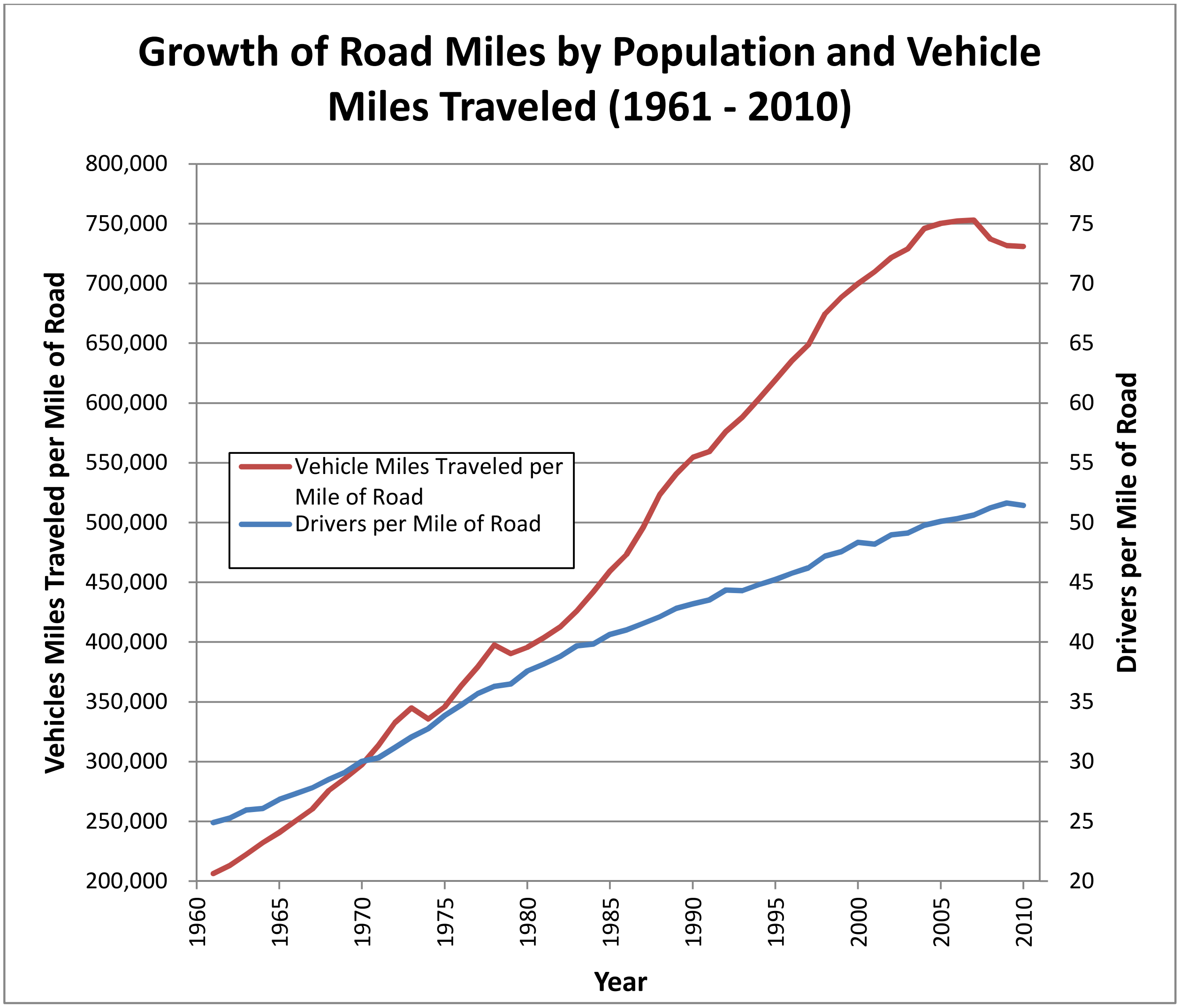


Figure 2: Population growth and road utilization has been outpacing the introduction of new roadways for the past 50 years (Federal Highway Administration, 2012)

Rising Energy Costs

Though much more volatile than the economy in general, energy costs have been rising alarmingly over the past ten years. Petroleum based fuel sources lead this trend, though the impact of the 2008 recession gave their rapid climb some pause. Interestingly, electricity's increase, though more rapid than the rate of inflation over the general economy, tracks the rate of inflation closely, and is the most economically stable of the reasonable fuel sources over the long term. Further, with the flexibility of electricity generation, as new methods of energy production are discovered, it is much more likely that electricity will continue to closely track the general economy and avoid the volatility of combustion fuels. (Bureau of Labor Statistics, 2012). .

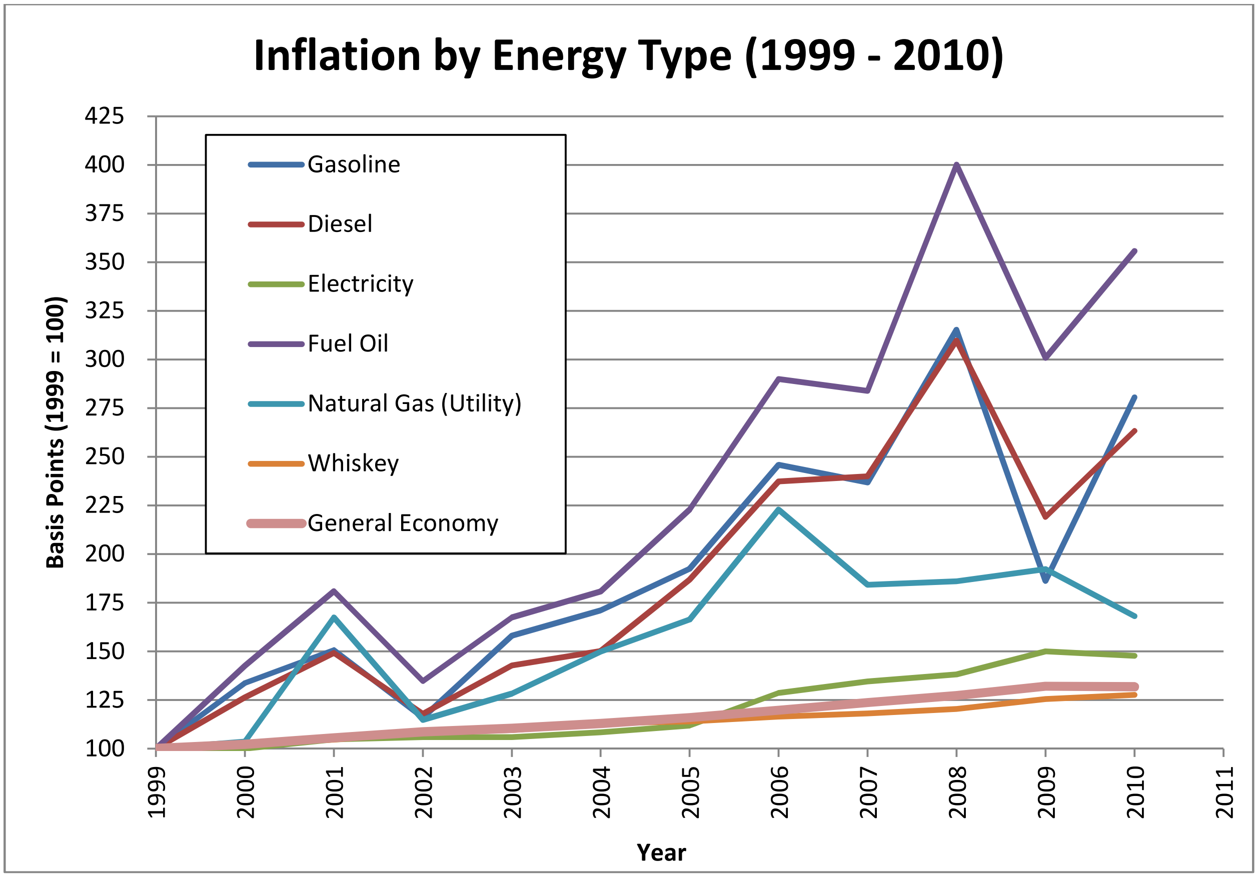


Figure 3: The rate of inflation for petroleum based energy sources is dramatically outpacing the growth of the economy and the rate of inflation for alternative transit energy sources (Bureau of Labor Statistics, 2012)

Mass Transit Acceptance

Judging by the rate of adoption, mass transit use in Silicon Valley (as represented by the San José-Sunnyvale-Santa Clara metro area) has failed to capture the interest of the population. Despite having similar populations, Silicon Valley residents opted to use mass transit at one fifth the rate of the nearby San Francisco-Oakland-Fremont megapolis (McKenzie, 2010). Nationally, mass transit only accounts for 5% of the total work-related trips taken by travelers. Alarmingly, the utilization of mass transit decreased in the region from 2008 to 2009, further highlighting the failures of existing options. Interestingly, more than 70% of the vehicle miles traveled in the region are consumed by individuals in their personal automobile. A proper mass transit system, one which could be made attractive to the bulk of the citizens utilizing the roadway system, would extend the useful life of the region's roads for decades. (US Census Bureau, 2011)

Considering America is unable to support its current growth path utilizing only the automobile, and the failure of existing mass transit options in the Silicon Valley region, another method must be found to meet the growing transit needs.

Automated Transit Networks (ATN), Personal Rapid Transit (PRT), and Other Considerations

ATN

With the advances in technology over the past century, it is now feasible to create and automated transit network (ATN). An automated transit network is a mass transit system comprised of vehicles and guideways which exhibit the following characteristics (Carnegie, Voorhees, & Hoffman, 2007):

1. Automatically controlled vehicles which travel to their destination without human intervention
2. On-demand service. A vehicle arrives when summoned, rather than on some predetermined schedule.
3. Supervisory safety and availability monitoring. The state of each vehicle in the system, and all of its subsystems are continually and automatically monitored for state and optimal function.
4. Non-stop service to the destination. Basically necessitates stations which are not on the main line of transit (called offline stations)
5. A discrete guideway, separate from existing roadways

PRT

Personal Rapid Transit is a subset of ATN focused on smaller vehicles targeted at approximating the automobile experience (as opposed to Group Rapid Transit (GRT), which more closely approximates a Van Pool). A PRT exhibits these additional characteristics (Carnegie, Voorhees, & Hoffman, 2007), (Irving, 1978):

- Small vehicles targeting one to six riders.
- Vehicles able to function around reasonably tight turns.
- Light weight vehicles to minimize energy and guideway support needs.
- Private ridership. There is no expectation that a vehicle will be shared between strangers.

Additional Considerations

Though not an absolute necessity for consideration as an ATN or a PRT, there are a few design dictates which are common amongst most implementations and are considered vital to address the looming troubles with the existing transit infrastructure (Carnegie, Voorhees, & Hoffman, 2007):

- Electric vehicles. Electric motors can be crafted to higher efficiency than gasoline motors, and by decoupling the motor technology from the fuel source, advances in fuel source technology can be leveraged over time

- Elevated guideways. Elevated guideways can take advantage of existing transit corridors, easing the implementation.
- Automated rebalancing of vehicles through the system to anticipate demand, and ensure rapid supply during times of imbalance (such as when there is significant migration towards a sporting event or during commute hours)

Interest in PRT in the Silicon Valley/Bay Area

That there currently exists strong interest in research and future PRT development taking place at San José State University may prove to be a key component in driving this technology forward in the Silicon Valley and Bay Area. Areas where such an interest and market exists are Mountain View and the City of San José.

Mountain View

In 2009, Advanced Transit Systems (ATS), a United Kingdom-based PRT company, made an attempt to convince the Mountain View City Council to consider PRT as a viable transportation system to connect the downtown train station, National Aeronautical and Space Administration (NASA) Ames and Shoreline businesses. The 15-mile route system they proposed starts at the transit system and ends at the Google campus with a total of 40 stations in and surrounding Shoreline and Moffett Field. (DeBolt, Mountain View Considers Bold New Transit System, 2009)

Given current transportation patterns, it is anticipated that within the next 10 years, the interchange between Highway 101 and 85 will become hopelessly gridlocked, and an ATN public transportation system will help to prevent this issue. The system which was proposed to cost $7-15 million per mile would be capable of transporting over 3,400 people per hour. (DeBolt, City considers PRT system, 2009)

This proposal has been well-received by the city and there has been growing support for such a system especially with the advent of the autonomous vehicles which Google is currently developing out of their campus.

SJ RFI and the San José Department of Transportation Consultant Study

The Santa Clara Valley Transportation Authority (VTA), Santa Clara Country and the City of San José in June 2008 began an analysis of the feasibility of putting an ATN system at the San José International Airport. The proposed system would connect the airport with the existing VTA light rail system, Cal-Train, and a potential BART extension to Santa Clara (proposed for 2025). It was estimated in the report that such an Automated People Mover (APM) would cost the city $967 million for the two-mile system—due to the high cost the APM was rejected. (Arup North America, 2012)

Instead, in August of that same year, the City issued a Request for Information (RFI) to entice other firms around the world to make offers to build a similar system. This RFI resulted in responses from 17 different companies, and in discussions with various ATN firms, consultants and independent researchers that this technology was ready for deployment. The VTA Board voted in support of ATN and authorized $4 million to develop a system to connect major transit systems currently existing within the city to the Mineta San José International Airport (Price, 2010). The consultants on this team came from Aerospace Corporation, which had extensive knowledge of ATN, and Arup, a company that had managed the implementation of this type of system at the Heathrow-London airport. (A White Paper on the Status, Opportunities and Challenges in Developing San Jose's Automated Transit Network (ATN) Project, 2008, p. 10)

The results of this study were released in October 2012 by the San José Department of Transportation about the feasibility of ATNs in the city. The main focus of the system proposed was to service the Norman Y. Mineta San José International Airport.

The conclusion of the report was that a PRT system in the city of San José would be beneficial but the full merits and disadvantages were not fully realizable at this time. The technology as a whole is in its infancy and despite the fact that the technology has existed for decades such a system has not been completely validated. At present time, despite interest in the system and the various local start-up companies which exist in the area, such as Unimodal, who are making progress in the area, there is still too much that is still unknown about how the system would actually operate. (Paige, 2012)

Competitions

Solar Sky Ways Challenge

Another motivating goal for this project was to enter the Solar Skyways Challenge. The Solar Sky Ways Challenge is a multi-disciplinary competition created and judged by The International Institute of Sustainable Transportation (INIST, 2013) challenging teams of university students to propose and prove the viability of a solar-powered ATN. (INIST, 2012) By providing a $10,000 USD prize to the two teams with the best design at Podcar City 7 in the fall of 2013, INIST is attempting to push ATN technology closer to true implementation.

As stated by INIST in the defining Solar Skyways Challenge, 2012-2013document, the goals of the Challenge are:

1. Raise awareness of the necessity to support innovative transportation solutions beyond cars, and the possibilities that exist to do such
2. Increase the involvement of the academic community in addressing current transportation-linked infrastructure issues and needs
3. Encourage regional undergraduate and graduate students to contribute to and influence the process of creating more sustainable transportation solutions in the Bay Area.

4. Develop an awareness of and an interest in solar-powered ATNs as a vital and important area for academic research and future careers.

Specifically, INIST is challenging the teams to meet investigate and propose solutions for the following areas:

1. Technical – prove viability
   a. Create a model of the physical systems necessary for an ATN being mindful of power requirements
   b. As much as possible, the system should be solar powered.
2. Civic – prove suitability
   a. Design an ATN network for a real-world location and prove its viability
   b. Work with civic planners to understand the legal framework and political process necessary to successfully implement such a system
3. Societal – prove acceptability
   a. Create and carry out a valid poll to identify the most pressing concerns the average person may have for or against such an ATN
   b. Actively work to evangelize ATN for the local area
4. Artistic – prove transit can be beautiful
   a. Minimize the negative visual impact of an ATN within the public space
   b. Beautify the guideways and vehicles to increase their acceptability to the public.

Final submissions are due to INIST on July 31, 2013

Chapter 3: Objectives

The primary objective of the SMSSV project is to design a fully functional ATN for the Silicon Valley based on personal rapid transit.

A secondary function of the SMSSV project is to submit the fully designed ATN system to the Solar Skyways Challenge 2012-2013 competition.

These two goals ultimately lead into the need for a full definition of specifications and constraints to the SMSSV ATN system. One such example of these constraints is the fact that the system's power source will only be utilizing solar power. Establishing these constraints and specifications will make it easier for this group as it moves forward in the system design process.

The task of designing an ATN system would be fairly daunting if it were not for significant research and analysis on previous ATN systems. The team researched and analyzed past and existing ATN technology elements to select the components most appropriate for this system.

One important aspect that must be considered when designing a viable ATN for Silicon Valley involves the location of an operational corridor where the guideways and stations will be placed. The selection of an operational corridor for the ATN is essential because it defines how the system will impact and improve the area. For example, a corridor that is notorious for congestion would be an excellent choice to place the ATN system.

If we are successful in accomplishing these objectives, the ATN will be able to provide a solution to traffic congestion in the Silicon Valley. Traffic congestion is a major problem in the area due to factors such as existing residents, commuters, high-tech companies, and just the sheer amount of vehicles on the road. All of these factors combined contribute to the traffic congestion not only on work days, but also on weekends at places like shopping malls and plazas.

Chapter 4: Structure of the Team Project

This cross-disciplinary team was structured into several teams focused on different functional areas. These teams were led by a team lead and the team leads in turn reported to a general project manager and treasurer. The functional area descriptions follow:

Cabin Design

- Design the cabin and exterior of pod
- Design for optimum performance and safety
- Adhere to legal guidelines and regulations
- Consider aesthetics

Propulsion

- Make propulsion system modular for ease of access and use
- Plan for middle to high speed travel
- Design an efficient, low-cost, low-energy propulsion system

Station Design

- Design aesthetically appealing station
- Determine most efficient way to direct traffic in and out of stations
- Adhere to legal guidelines and regulations

Solar

- Design and size a solar system to power the ATN system
- Maximize energy from solar system
- Minimize costs
- Consider aesthetics

Control Systems

Creation of any software related systems to automate the PRT functionality, including:

- Autonomous pod control
- Master pod controller
- Safety and preventative monitoring
- Ticketing

Urban Planning

- Assess suitable potential corridors and locations for ATN infrastructure
- Assess the zoning codes and general plans of Santa Clara County cities and unincorporated local authorities for locations capable of supporting fixed guideways system
- Locate five largest potential trip generators and the closest existing major transit hubs and nodes

Chapter 5: State-of-the-Art / Literature Review

With guidance from the projects advisors and several online indices, each functional group reviewed the literature related to their areas. Overviews of PRT, ATN, and transit general transit concerns were reviewed to provide context for the specific areas.

Cabin Design

The design developed by the cabin design team has been influenced by the research in the design specifications of system models and concepts which have been developed. The three companies that were focused on were Beamways, Ultra and H-Bahn.

Beamways

Beamways AB was established in January 2008. Two years prior to the formation of Beamways, Bengt Gustafsson, CEO and one of the founders, had developed a complete PRT concept. (Beamways AB, 2008)

The Beamways cabin seats three people, meets Sweden's ADA complaints and has room for bikes. A three seat configuration was chosen because people tend to travel in smaller groups, but if more people wish to travel in the cab there is plenty of standing room. (Requirements on the Beamways Cabin, 2012) He also pointed out that since this is a system with many destinations, but little to no stops in between, having large groups of people traveling to a similar destination would not occur often enough to increase cabin capacity. One of the requirements of the system is that passengers should be seated to allow for faster vehicle speeds, sharper turns and faster vehicle acceleration and deceleration.

Since the design must meet Sweden's ADA regulations, there is already adequate space built in for luggage and other items that passengers might bring aboard. An attractive feature and a key selling point that was built into this design was a space for bikes. For the first couple of years after this system is built and in service, it will not be serving all areas of any city. Combining bikes and this PRT system would encourage people to use the system.

One major feature to this cabin design that addressed wheelchair access, is foldable seats. In the United States, one of the major requirements for any public vehicles is that a wheelchair must be able to back up to a wall when vehicle is in motion. Physically folding a chair is a challenge for many wheelchair occupants; therefore, Beamways' design includes chairs that fold when a button is pressed.

To address safety and quality of service, Beamways uses double sliding doors on both sides of the cab. The height and width of the Beamways cabin are designed to have minimum impact on the guide way, yet still not be greatly affected by the cabin's aerodynamics. A wider cabin design would put more stress on the T-bar holding the cabin to the boogie, resulting in the need for a stronger and more expensive T-bar. A longer cabin design would decrease system and station capacity. The flat top in the exterior design decreases stress in the T-bar holding the cabin because it can be attached closer to the guide way.

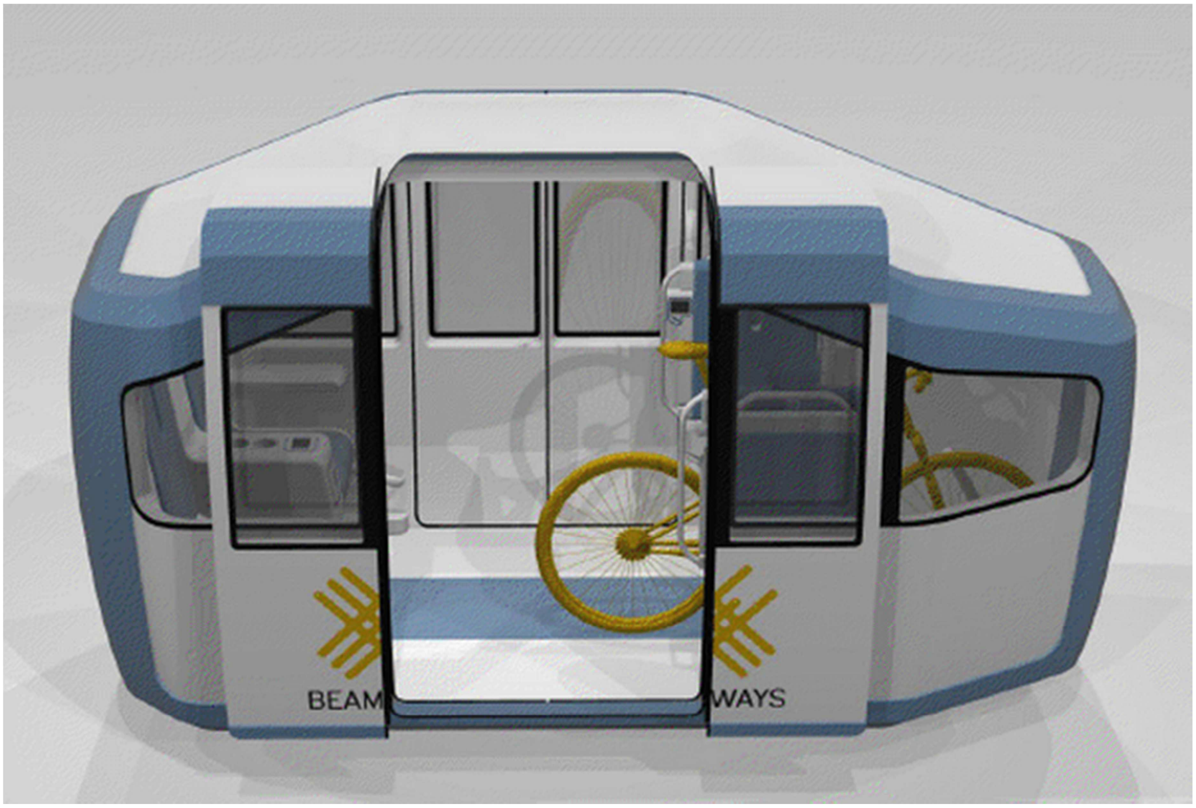


Figure 4: Beamways Cabin Design. The cabin design of Beamways uses double doors on each side to ensure quality of service and safety to its passengers. (Requirements on the Beamways Cabin, 2012)

Ultra

A PRT system that is currently functioning at Heathrow Airport in England was designed by Ultra. The Ultra cabin shown below was designed to hold four passengers plus luggage. While the current bench seat layout used at Heathrow airport utilizes a four seat configuration, Ultra's cabin design can be customized to accommodate up to six seated passengers.

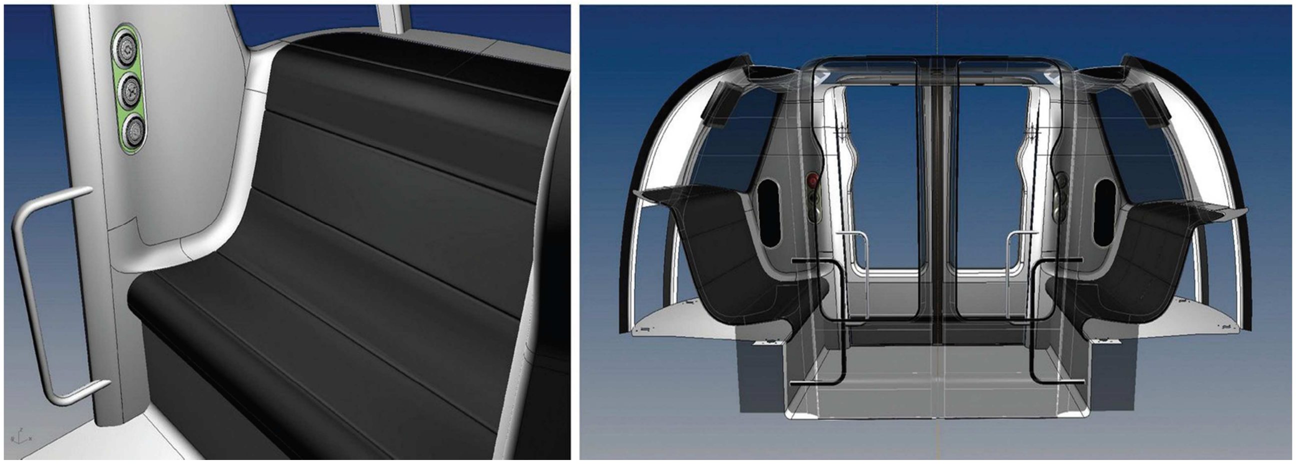


Figure 5: The interior layout of Ultra's cabin design features bench seats which face one another. (Ultra Global PRT, 2011)

The cabin weighs 850 kg (approximately 1875 lbs) when empty but its maximum mass at capacity is approximately 1300 kg (approximately 2886 lbs). The length of the cabin is 3.7 m, 1.47 m. width and 1.8 m. height (approximately 12 ft x 4.8 ft x 9 ft, respectively).

The interior of the cabin features flat floors that align with that of the station to allow for wheelchair, so that the vehicles comply with the United Kingdom's Disability Discrimination Act (DDA) and they also comply with US ADA requirements. The double door opening is about 0.9 m (3 ft) wide which makes it easy to accommodate wheelchairs, bicycles and large cargo.

The interior is illuminated to allow passengers to enjoy reading; it contains a liquid crystal display (LCD) to relay relevant trip information to occupants; and it provides heating, ventilation, and air conditioning to provide a comfortable ride. Additional notable features of the vehicle include an illuminated door, control, communication, and alarm switches. In the case of emergency, there is a two way communication system to allow passengers to contact the control team; the cabin also features an emergency exit that is accessible from inside and outside the vehicle. (Ultra Global PRT, 2011)

H-bahn

H-Bahn is a suspended group rapid transit (GRT) system that has been in operation in Germany since December 1993. Each vehicle has a 45 passenger capacity with a 16 seat layout illustrated by below and the interior space to further accommodate 29 standing passengers.

One of the most notable features of the interior are special compartments that house the control and monitoring systems and the ability to operate the vehicle from inside if necessary.

Figure 5: The H-bahn cabin features 16 seats which can accommodate multiple sized parties and the spacious layout allows for standing passengers. (H-Bahn 21)

The exterior features large windows and two pairs of sliding doors. The exterior of the cabin which measures at 9.2 m in length, 2.2 m width and 2.6 height (30 ft, 7.2 ft, 8.5 ft measurements, respectively) is built from extruded aluminum which provides for high corrosion resistance to weather conditions while providing the necessary stiffness at a low weight. The empty vehicle weight is 8,455 kg (18640 lb) and provides a maximum weight capacity of 13,378 kg (29493 lb). (H-Bahn 21)

While H-Bahn vehicles are substantially larger than typical PRT systems researched, this system is of note since it is a suspended system that is currently operational.

Vectus

Vectus is a UK-registered company which is currently operating in Korea and Sweden. Its system is shown in Figure 7. Its compact cabin design measures 3.5 m in length, 1.9 m width and 2.2 m height (11.5 ft, 6.2 ft, 7.21 ft, respectively. Its design features heating and air-conditioning, individual seating, dual displays and reading lights, and provides a comfortable and luxurious trip to the passenger as well as wheelchair accommodations. The cabin provides space for luggage and other cargo that the passenger might be carrying. Special comfort features include armrests and in-seat entertainment systems.

The cabin is fire and graffiti resistant and composed of pre-preg phenolic GRP, a composite material. In addition, Vectus offers the three layouts for the interior, the most basic of which is shown below in Figure 7. (Vectus Intelligent Transport)

Figure 6: Vectus Cabin Design. This interior design concept is just one of three that has been developed by Vectus. (Vectus Intelligent Transport)

Propulsion

Methods of propulsion for this ATN system will be discussed in this section of the report. The most commonly utilized propulsion methods for automated transit networks (ATN) to date are linear induction or rotary motor propulsion systems. Although magnetic levitation (maglev)

Figure 7: Shanghai Magnetic Levitation Train (Shanghai Maglev Transportation Development, 2005)

exists as a propulsion method for larger scale transportation systems (i.e. Shanghai maglev train) it has not been utilized as a propulsion method for ATN systems. Conforming to the standard of public transportation, all proposed or currently available pod car propulsion systems operate with electricity as its primary source of power. Therefore, all linear of rotary motor propulsion systems will be powered by electricity. Within the context of this report, the term "rotary motor propulsion" will be a reference to electric motor powered transmissions. These transmissions consist of an electric motor that provides torque to rubber or steel wheels through a series of gears, chains, or transmissions. While rotary motors are currently used in a multitude of transportation solutions (i.e. BART, electric vehicles) there are alternative propulsion systems that are beginning to become more viable. An example of potentially usable technology is the linear induction motor. (Shanghai Maglev Transportation Development, 2005) (Ultra Global)

Figure 8: ULTra Personal Rapid Transit Pod Car (Ultra Global)

The first example of possible propulsions system types is the rotary motor system utilized by the ULTra system located at London's Heathrow Airport. Its design is composed of rotary motors interfaced through a set of rubber tires in contact with a concrete pathway. This design is the closest adaptation of traditional transportation, which allows initial construction costs of a pod car system to be kept relatively low when compared to a linear induction motor system. Notable features of their propulsion system include:

- '7kW' synchronous AC drive motor
- Fixed gear ratio
- Front wheel drive
- Regenerative braking
- Maximum speed of 25 mph
- Turn radius of 5 m

Due to the unavailability of the system's design specifications, it can only be extrapolated that the ULTra ATN systems utilizes rotary motor propulsion systems because of their lower (compared to linear induction motors) upfront cost and power requirements (Ultra Global). Since the ULTra ATN pod cars receive power from their on-board batteries, it can be assumed that their decision to utilize a rotary propulsion system stems from its relatively low power consumption (when compared to other methods of propulsion). Essentially, rotary motor propulsion systems rely upon an electric motor (or series of electric motors) to transmit power to

the track through a drivetrain.

The second example of a propulsion system classification is the linear induction motor system currently being implemented by Vectus and SkyWeb Express. The main directive that influenced the Vectus ATN's propulsion system selection was the desire to operate in extreme weather conditions. Most notably, LIM's provide a propulsive force that is independent of the traction between the tire and track. This characteristic is most useful in cold weather climate conditions, where an icy or wet track would reduce the effectiveness of a traditional rotary motor propulsion

Figure 9: VECTUS ATN Pod Car (VECTUS, 2011)

system (VECTUS, 2011). SkyWeb Express utilizes linear induction motors as a form of transportation and shares several similarities with the Vectus propulsion system. The key differentiating facts are the adaptations for increased reliability in the Vectus systems and the interface to the track. Skyweb Express uses rubber wheels on the guide way instead of steel wheels on a rail as in Vectus. Currently the SkyWeb Express ATN system constructed a partial prototype with full functionality, proving the application and validity of linear induction motor propulsion systems (Skyweb, 2007). Conceptually, linear induction motors utilize the manipulation of magnetic fields to create a propulsive force that can accelerate the pod car.

Although different in theory, both linear induction and rotary motor propulsions systems are almost freely interchangeable due to the similarities of the bogie (apparatus that houses the propulsion system and supports the pod car on a track). Simply put, a linear induction motor is a flattened out electric rotary motor that outputs a magnetic force instead of a mechanical force.

Structure

Several suspended and supported PRT networks were studied in detail in terms of their structures/guide way design in order to understand the technology that currently exists or is currently under development.

Cabintaxi

Cabintaxi PRT system, shown in Figure 10. Cabintaxi PRT system . (Cabintaxi PRT System, 2012). Cabintaxi PRT system utilizes a double track guide way that allows the vehicles to ride both supported on top and suspended below the guide way. This two-way access on a single guide way introduced a way to increase through-put on a single guide way and reduce the total mileage of structures in the system. The guide-way consists of a box girder, completely encapsulating the bogie, and provides guidance and support for vehicles.

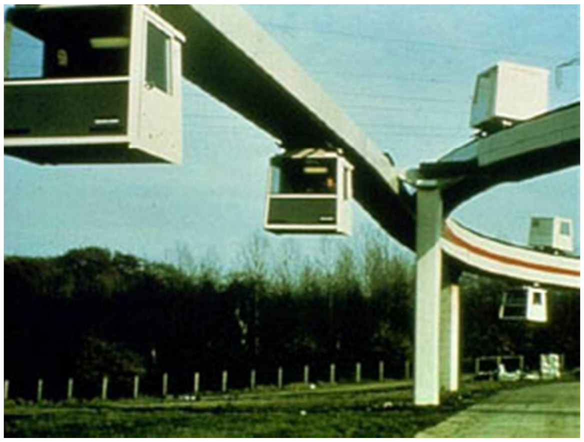


Figure 10. Cabintaxi PRT system (Cabintaxi PRT System, 2012).

Cabinlift

Cabinlift, shown in **Error! Reference source not found.**, is an automated PRT system that utilizes the experiences gained from Cabintaxi (Burger M. , 2010). The track is a box section bridge completely encapsulating a bogie that rides on rubber wheels, as well as the busbars, brakes, secondary conductor for the drive units, main and emergency power line, heating, and communication line. Cabinlift, as a rule, utilizes reinforced concrete for their supports.

Figure 11. Cabinlift PRT system (Burger M. , 2010).

SIPEM (Siemens People Mover System) H-Bahn

As mentioned earlier, the H-Bahn is a suspended, automated monorail system developed by Siemens, currently in operation in Dortmund and Düsseldorf, Germany (SIPEM - Siemens People Mover System, 2010). Their guide way consists of a hollow rectangular box girder with a slit in the bottom, allowing motorized bogies to sit on rubber wheels in the girder while carrying the cabin bellow, as seen inFigure 12. H-Bahn PRT system. Each cabin vehicle requires two motorized bogies. The girder completely encapsulates the bogies so that they are protected from the elements. All components of the structure and guide way are pre-fabricated and assembled on location. Prefabrication provides a major advantage for this system as compared to other systems where the guide ways area fabricated on site. H-ban is currently still in operation (H-Bahn Dortmund, 2013).

Figure 12. H-Bahn PRT system

MISTER

(Metropolitan Individual System of Transportation on an Elevated Rail)

The MISTER PRT system is an automated transit system that utilizes a unique truss-rail infrastructure (seeFigure 13. MISTER PRT system) that allows vehicles to switch from rail the rail with ease and has the capability to lower vehicles down to street level (MISTER, n.d.).

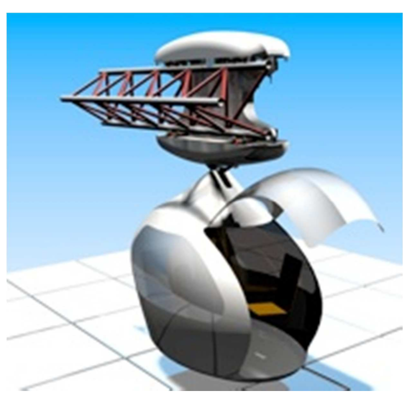


Figure 13. MISTER PRT system (MISTER, n.d.)

SkyTran

SkyTran, a two-passenger suspended automated PRT system currently under development by Unimodal Inc. in collaboration with NASA, utilizes a passive, magnetic levitation system for their guide way. This system was chosen by the design team due to fewer moving parts, which significantly reduces the cost. The guide way completely encapsulates the bogie holding the vehicle, keeping the vehicle safe and secure while achieving higher speeds.

Station

Off-line Stations vs. the Alternatives

Most public transportation systems that run on rails do not use an off-line station system. For most public transportation systems that run on rails, the vehicle travels to each individual stop, stops, unloads and loads passengers and then continues on with its journey. There is no way to bypass the vehicle while it is stopped at a station because it is stopped on the mainline. Systems that are designed in this manner are extremely reliant on vehicles not stopping at a given station for a large amount of time because it will have a significant impact on the throughput of the system on the rest of the vehicles in the system.

A system with off-line stations like the one shown below separates the station from the mainline. When a vehicle wishes to stop at a given station, the vehicle leaves the mainline on a sub-line and decelerates to the station. The vehicle then unloads and loads its passengers and accelerates back to the mainline. Off-line stations decrease travel time because the vehicle does not impede the mainline, allowing other vehicles to keep traveling to their destination.

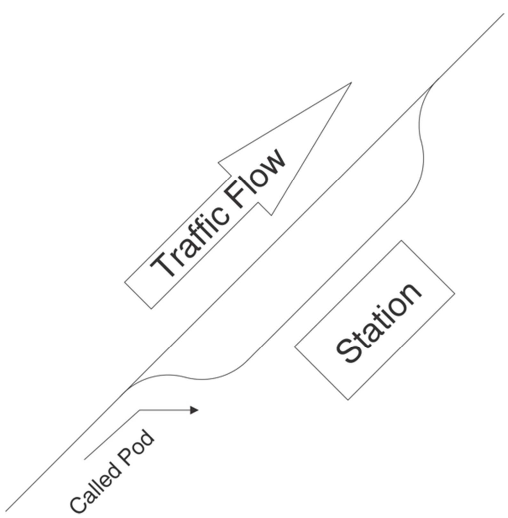


Figure 14: Representation of an Offline Station

Linear Station

The concept behind the linear station is simple. A vehicle pulls up to the station, unloads and loads passengers and then continues on to it next destination. It is used for buses, trains and a number of the PRT stations that currently exist. A linear station is an ideal setup for high capacity vehicles like buses and trains that travel to every stop along their route or for low traffic impact PRT stations.

Angled-Berth Station

In the case of a linear station, the vehicles behind other vehicles at the station are dependent on one another. To demonstrate an issue with linear stations, let us assume there are four vehicles stopped at the station. The vehicle closest to the mainline has passengers that are boarding, but very slowly. The three vehicles behind the first vehicle have passengers waiting to go to their next destination, but cannot because the first vehicle is in their way. This leads to a buildup of congestion in the station and a decrease in the quality of customer service. An angled-berth station, as shown in Figure 15, eliminates this issue. Instead of vehicles lining up behind each other, they pull into berths before unloading and loading passengers. This setup decreases travel time because each vehicle can leave when it is ready and not when the vehicle in front of it is ready. The PRT system by 2getthere in Masdar City and the Ultra system at Heathrow Airport currently use this type of station arrangement..

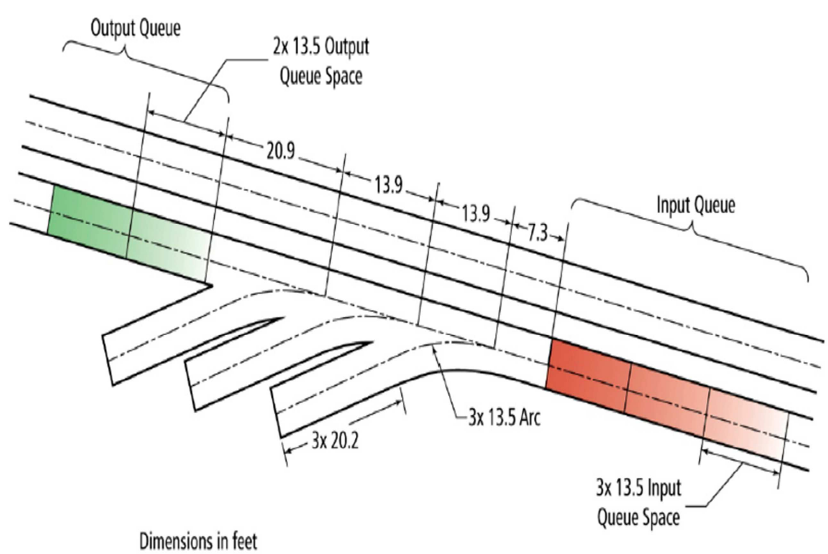


Figure 15: Angle Berth Station Design (Paige, 2012).

Design Specifications for the SVSSM ATN System

Ideally, passengers would not be spending much time in the station because the podcars would come as soon as they are called by the passenger. For that reason, the station is going to be modeled after and look more like the Ultra station at Heathrow Airport, rather than a more extravagant airport. This will also help to save money overall. However, the station will still have the basics such as a place to sit and a trash can. In addition there are governmental requirements that must be met, which are listed below:

- Gap between the cab and platform is no wider than 3 inches and the height from the cab to the platform is no higher or lower than 5/8th of an inch
- Appropriate space for wheelchairs to move easily within the station
- Ramps and lifts placed where needed
- Proper notifications that address the needs for disabled, that consisting of appropriate signs, markings and verbal notifications

Vehicle Storage

Vehicles will be sent to offsite stations and garages under high traffic stations when they are not in use. Vehicles sent to offsite locations can be stored, cleaned, and receive any necessary maintenance before being brought back into service. Vehicles stored in garages under high traffic stations can be called up when needed. For many public transportation systems, this method is more than adequate to address vehicle storage needs.

A continuous guideway will take vehicles to and from off-site stations and garages, so that a break in the guideway will not exist. This eliminates the chance of guideway and vehicle complications, ensuring a safer system.

Solar

As of 2012, there are no solar-powered ATN systems that have been constructed or are currently in construction. However, there are several vehicles that may be considered precursors to the idea. The World Solar Challenge (http://www.worldsolarchallenge.org) in Australia and the American Solar Challenge (ASC) (http://americansolarchallenge.org) in the United States are both competitions to create a car that may have the ability to replace the cars in common use today. Originally, the challenges were intended purely as a race from one point to another. As the cars evolved they began to break freeway speeds, becoming less safe and less constructive for public use; that is, the size of the cabin stayed small, and the cars would never approach a model that would be fit for public use. A team from the University of Michigan entered a car in the ASC that had the ability to exceed 105 mph, showing that solar powered vehicles are getting closer to being more than just a quirky invention. However, it is equally clear from Figure 16: Quantum, University of Michigan's Solar Powered Car (Source: http://solarcar.engin.umich.edu/the-car/) that the design of the vehicle still has a ways to go before it is something the consumer can use.

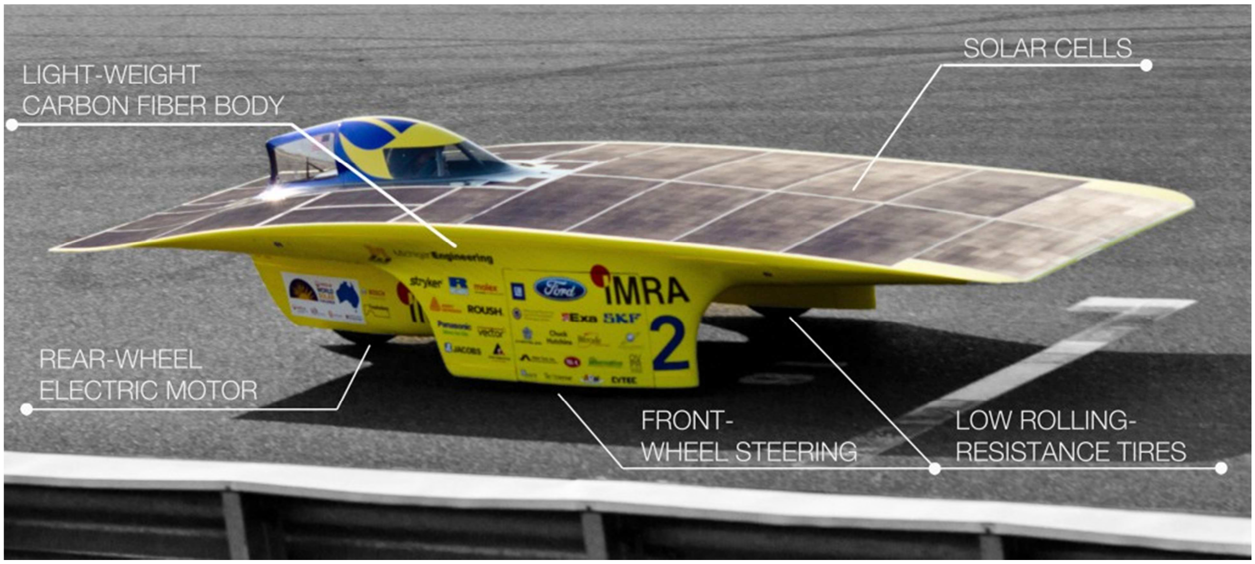


Figure 16: Quantum, University of Michigan's Solar Powered Car (Source: http://solarcar.engin.umich.edu/the-car/)

The solar car has one significant drawback that ATN does not – it must contain all solar cells within the space of the vehicle itself. It should be noted that other than ATN, there is no current transportation infrastructure that could utilize its space as efficiently as an elevated track. This is why a completely solar powered vehicle has not yet been possible on a large and marketable scale.

Despite this, few ATN systems argue that adaptability to solar use is one of their greatest strengths. Not one of the respondents to San José's RFI on the subject included solar panels as for the primary energy source for their system. Some companies included solar as a possibility that could be added to the pre-existing system, but it was not mentioned in depth, nor was it strongly pushed as a concept that should be implemented. Some that did not respond to the RFI do believe in solar technology, including Santa Cruz PRT and SkyTran. However, neither has provided much information regarding their implementation of the system. They have both claimed that it is possible to construct a 100% solar powered ATN.

The most in-depth explanation of those that mentioned using solar panels to power their pods was the RFI from Beamways. One important question Beamways asked was how the electricity should be transferred from the panels to the system. Using the same electrified rail as the one powering the cars could potentially be cheaper because it save on the cost of additional cables throughout the entire system. However, the downside to this is that there would be few off-the-shelf parts suitable for this, such as the inverters/converters; most would have to be customized to the specifications of the system. Additionally, there is the potential for interference if the rail is shared.

The question of panel orientation or tilt is briefly addressed, with various ideas of how to solve the potential problems. A panel tilted toward the sun (south in San José) not only contributes more power to the system, but allows rain and other soiling to run off and keep the panel running efficiently. The problem is when it is less desirable to tilt the panels. For a North-South running track, panels with significant tilt will shade each other, causing the design to either take shading into account or to have greater spacing. Both of these choices greatly reduce the power output of the modules.

It is possible to use a thin film module that avoids the standard orientation issues. Thin film can be bent to create a more cylindrical shape, which allows for the sun to always be hitting at least one part of the panel at the proper angle at all times. Since thin film is cheaper, it can be done more affordably, but at the cost of efficiency.

In some situations, it may be beneficial to use a less obvious method for arranging the panels. For example, there will be situations where a portion of the track may frequently be shaded by trees or buildings. It wouldn’t be prudent to put any kind of modules on the track in those sections, but there might be alternatives. In the case of tall buildings, it may be possible to arrange for some panels to be put on the roof of the buildings creating the shade. Trees would be more problematic, but it may be possible to make up that energy on other, more empty and less shaded portions of the track. It may be useful to put the panels on the sides of the columns, or on the ground near the supports, if the ground area is available for use.

Control Systems

Centralized Control (Synchronous)

One master controller determines the state and choreographs the entire system.

Description

With a centralized architecture, one heavily integrated system performs all command and control functions. In this environment, all mechanisms are simple extensions of the controller, functioning as input/output devices to the central "brain".

Benefits

Centralized control has the capability to provide a global view of the system as a whole. These systems are architecturally less complex to build, design, and debug. With a focus on one highly integrated system, the architects and programs are only required to create one code-base with a single end-goal. Since every unit functions as an I/O device from the central control's perspective, there is only a single communications stack which must be scheduled. This creates a single fundamental problem to focus upon with only one set of partitioning. Further, the approach to such a problem is well known and much has been written about said development.

With minimal intelligence in the pods, they will generate the least expensive pod-control electronics. Even in this case, there would need to be some communicating circuitry which communicates with the master control and deal with its commands, but that circuitry could be as simplistic as a state machine, polling the master for its next directive.

With one system in control of the entire network, finding and diagnosing the state of the world is feasible and should suffer under no communications lag. The failure state of every device is easy to determine (shut down and stop moving), allowing central control to react to a problem with complete knowledge of the state of the world.

Flaws

The world has been leaving behind fully centralized systems over the past 30 years for several reasons. Central control systems do not scale well. At some level of complexity, the simple scheduling of directives to each node overwhelms even the most robust system's ability to communicate. Though such a system generates the least expensive pod costs, it generally nets the most expensive control system. In short, a centralized control system is more suitable for a small and simple transportation network (Berger 2011).

Analysis

In its purist form, a centralized system would be a disaster. Without intelligence in the car, every motion must be controlled from the central system. Predictably, as the system grows in size and complexity, the abilities of the master control must increase. At some point, the absolute limit in technology will occur, placing an upper bound on the complexity and size of this system. More despairingly, long before this limit occurs, the system will begin exhibiting inconsistent behavior as times of high demand receive a lower quality of service than times of low demand.

Reliability is explicitly not a concern with a central system. Though, at casual glance, there appears to be a single point of failure; there is no reason the central system cannot be built with many levels of redundancy (indeed where lives hang in the balance, three levels of redundancy are the minimum acceptable).

Examples

The Morgantown Personal Rapid Transit System can be taken as an example of a centralized PRT control system. This PRT system is centrally controlled with a combination of humans and automation making all decisions for the system. Since 1970s, Morgantown PRT system has shuttled 19,000 students and 7500 employees between campuses at West Virginia University (Gibson 2002). Morgantown PRT system has a record of uptime availability up to 98% with very few break downs, and in most, breakdowns were caused by mechanical problem from the vehicle (Albert 1983). Looking at a complex control system with the lack of technology from the 70s, Morgantown has demonstrated great reliability of its system. Another aspect to be considered is that Morgantown PRT only services five stops with an 8.65 mile total distance (Booth 2007). This is a relatively small model to be a good demonstration for a centralized PRT control system. However, as of 2010, Morgantown was still the only one of its kind.

Peer to Peer Control (Asynchronous)

Each unit within the system (pod, kiosk, etc.) is its own autonomous unit. The control is distributed across the entire unit-verse.

Description

In a peer to peer system, there is no true hierarchy amongst the systems, and every system contains the information necessary for its own autonomous operation. The units have localized intelligence sufficient for complete autonomous control. System level decisions are made by a voting or prioritization process which occurs through intra-node communication and some type of decision making tree (frequently an expert system of some type). One node communicates to the network when service is required which it cannot provide (such as a station requesting a pod), and through the same prioritization rules, some or many other systems answer.

Benefits

With each unit having significant intelligence, there is infinite scalability in processing power. Adding a unit increases the net capabilities of the system linearly.

Such systems have intrinsic fault tolerance. Since each unit is responsible for itself and for reacting to its operating environment, a failure in one place will be naturally worked around by those systems within the failing unit's operational sphere.

Flaws
As the number of systems increase, the raw complexity of the system and potential requirements for intra-node communication increases through the factorial of the number of nodes. This necessitates communications networks with ever increasing size or a willingness to partition the system into localized domains. Once a system is partitioned into localized domains, cross domain boundary handling becomes a significant problem.

Collating the state of the entire system into one view becomes an incredibly heavy process, made more difficult with partitioning. Due to communications delays, it is possible, nay likely, that a complete view of the system is never able to complete before the state of the system changes.

Since every unit must be able to autonomously function within its operational sphere and handle possible failure states with units outside of its control, the individual pod control system becomes rather complicated.

Predictably, a fully distributed system creates the most expensive pod controls, and necessitates a very robust communications network.

Analysis
Without some central authority to arbitrate between systems and to coordinate reactions to failure, a purely peer to peer system will be incredibly complex to implement. Further, the math governing the growth in necessary communications as the system scales creates an almost insurmountable scaling problem. One merely needs to look at the history of AppleTalk to see the communications trouble as the need for state communications increases.

Examples
The current automotive transit system works in this way, with rather complex humans functioning as the in car control system and a combination of traffic laws and the ubiquitous middle finger as the rules governing each units function and reaction.

The Hybrid Architecture (Quasi-Synchronous)

Description
The hybrid system would incorporate the benefits from peer-to-peer and centralized control systems. The system would inherit the central authority and maintain a certain level of world awareness on the nodes of the system. The authority will be able to coordinate between other external systems, such as ticketing with routing capabilities. The pods will have enough intelligence to be aware of the world and safely follow the routed path passed down by the authority.

Benefits
The authority, or master controller, will be able to make high level decisions for improved efficiency of the overall system and the pod intelligence will distribute fault tolerance across the

system in cases of crisis. The efficiency gained from the authority will allow better traffic flow for faster travel times. The pod intelligence will allow any safety related events to be handled directly with the least latency and the most independence of other systems.

For any form of transit, safety is the most important consideration when designing control systems. During the event of a catastrophic failure, the system must support the means of safely returning passengers to the nearest station. The peer to peer network between pods will enable any operational pods to safely return to a station without the need to communicate back to the master controller. In the event the master controller fails or long range communication is down, the close proximity of communication in the peer to peer network will have a much greater chance of being operational since each pod will have its own intelligence.

Flaws

Since the system incorporates a hybrid of design structure, the system is expected to be more complex to implement. The complexity comes from having more components and subsystems to design.

Analysis

While the system will be difficult to implement, the safety gained will tremendously help adoption rate. The fault tolerance would be much greater, and still enable having a central authority to maintain a hierarchy in the system. In the case of half the system being taken down, the pods will still be able to make it to safety.

Chapter 6: Design Specifications for the SMSSV ATN System

Cabin Design

Passenger safety is one of the most important concerns in the transportation industry. In order to prevent injury, the vehicle must be designed for crash worthiness. The vehicle must be able to sustain a crash impact for any reason (malfunctioning control system, vehicle stuck on guide way, etc.) and still allow for passengers to be safe. It is one of the constraints to design a pod such that the passenger cabin will remain intact and the passengers unharmed in the event of a crash.

A form of communication, such as through a protected two way intercom system between the pod and the system's control room, will be required in a variety of situations. For example, in emergency situations (collisions, fire, and stuck pod) passengers will be using the communication system to communicate their situation to the system's control room.

Two small fire extinguishers will need to be placed on both sides in the cabin so that small fires can be extinguished by passengers.

ADA compliance is a major requirement in order for this system to be established. In Section §1192.53a of the Access Board Transportation Vehicle Accessibility Guidelines (ADA Accessibility Guidelines for Transportation Vehicles, 1998), the doorway clearance must be a minimum of 32 inches across. The International Symbol for Accessibility on the cars must be displayed clearly on the exterior and interior of the pods, which is stated in Section §1192.53b. In Section §1192.53c, auditory and visual signals for when the doors are in motion must be used, such as the use of flashing lights mounted near the doors. As stated in Section §1192.173b, the gap between the pod and the station platform must be no wider than 3 inches and the height from the pod to the platform must be no higher or lower than 5/8 of an inch. Inside the cabin, the minimum clear space of 30 inches by 48 inches is required for wheelchair access and space (Section §1192.83a). Lastly slip resistant floors must be used to reduce the amount of injuries.

Propulsion

One goal of the propulsion design selection team was to make the system capable of high speeds. By doing this, the system will be more competitive with current on-road vehicles, and will have the opportunity to expand to increased distances. Although the cruising speed of the system has not been determined, the propulsion system will ideally achieve at least 50 miles per hour.

Another key design specification is the sizing of the LIM's. The weight of the vehicle is known, while the coefficient of friction and the acceleration speed were estimated for this system type

(The engineering toolbox, 2011). An acceleration of 1.125 meters per second squared is comfortable for passengers to experience (Pemberton, 2012). Using these variables, the maximum amount of thrust during acceleration and cruising was calculated. By minimizing the size of the motors, the cost of the system and the power consumption will decrease. The result will be a calculated power consumption calculation instead of an estimate from a previous design. In **Error! Reference source not found.**, the design specifications for a linear induction motor are shown.

Table 1. Propulsion Design Specifications

Design Variables	**Value**	**Units**	**BOE**	**Comments**
kinetic friction wheels	0.50		E	
rolling friction bogie	0.03		E	
static friction	1.00		E	
calculation weight	1133.98	kg	D	
cruise velocity	22.40	m/s	E	or 50MPH
number of coils per motor	10.00		D	
number of coil turns	100.00		D	
air drag	112.00	N	A	at 50MPH
friction force	223.00	N	A	
force required to accelerate	348.00	N	A	
cruising force required	335.00	N	A	
total acceleration force	571.00	N	A	
acceleration Wh/mile	158.00	Wh/mile	A	
cruising Wh/mile	281.80	Wh/mile	A	
width of laminations	0.20	m	D	
number of poles	8.00		D	
thickness of aluminum	0.01	m	D	secondary
pole pitch	0.10	m	D	
regular acceleration	1.125	m/s^2	D	
time to accelerate	73.00	s	A	to 50MPH
distance to reach cruise	816.00	m	A	to 50MPH
energy required to reach distance	465.80	kJ	A	
acceleration power	6.38	kW	A	
Power needed to overcome friction	4.98	kW	A	
peak current in one phase	8.30	Amps	A	
3-phase loss of power in rotor	173.00	W	A	
initial field velocity	0.22	m/s	A	
frequency of field	1.09	Hz	A	
slip velocity	0.34	m/s	A	at 50MPH
mechanical power plus power loss	14.09	kW	A	
synchronous velocity	22.60	m/s	A	
continuous braking force LIM	500.00	N	E	100% duty cycle

braking distance	568.99	m	A	
braking time	50.80	s	A	
peak braking force LIM	2900.00	N	E	30% duty cycle
peak braking distance	109.00	m	A	
peak braking time	9.73	s	A	
Power harmonic	3646.27	W	A	
Power stator	7482	W	A	
Power rotor	173	W	A	
Power developed	14090	W	A	
Power transmitted	1000	W	A	
efficiency	0.53		A	

While magnetic levitation designs exist that use little energy and generate enough thrust, as in Skytran, the technology has not yet been developed and tested enough to be certain about it capabilities. Skytran has estimated that they can achieve 100 Wh/mile energy use while cruising at 45 MPH. This is due to the unique propulsion and levitation system designed for the bogey, and the lightweight, 2-passenger vehicle. While on paper the propulsion system used by Skytran is optimal, there is not enough known about the design to pursue it.

Station

Ideally, passengers would not be spending much time in the station because the podcars would come as soon as they are called by the passenger. For that reason, the station is going to be modeled after and look more like the Ultra station at Heathrow Airport, rather than a more extravagant airport. This will also help to save money overall. However, the station will still have the basics such as a place to sit and a trash can. In addition there are governmental requirements that must be met, which are listed below:

- Gap between the cab and platform is no wider than 3 inches and the height from the cab to the platform is no higher or lower than 5/8th of an inch
- Appropriate space for wheelchairs to move easily within the station
- Ramps and lifts placed where needed
- Proper notifications that address the needs for disabled, that consisting of appropriate signs, markings and verbal notifications

Solar

Power and Energy Estimates

Peak power estimates are needed to properly size the solar power and distribution systems. Literature suggest that power estimates are highly dependent on the specific ATN, as a network can vary in length, passenger demand, propulsion design, vehicle capacity and speed, and many other parameters (Irving, 1978; Anderson, 1988; Paige, 2012). Due to such parameters not being completely defined for the SuperWay the solar team's approach is to research the topic, come up with estimates that are based on general ATN's, and verify them with independent calculations. Energy calculations will be based on energy requirements per mile of guide way.

The most detailed report on the matter researched was the ATN feasibility evaluation on the San José Mineta International Airport prepared for the San José Department of Transportation (Paige, 2012). According to the evaluation, a one system size fits all design approach is not adequate, as the design of an ATN "is completely dependent on the particular application for which it is intended" (Paige, 2012). There is a lot to learn from their study as it contains much useful information that is applicable to ATN's in general. Regarding ATN energy estimates, their results can be used to design an ATN that uses proper thermal management to reduce energy consumption. Some highlights from their study:

- Heating, ventilation, and air conditioning (HVAC) power requirements are approximately the same magnitude as those for propulsion.
- The higher the number of occupants in the vehicle the more power is needed to cool the vehicle, and the less number of occupants in the vehicle the less power is needed to heat the vehicle.
- Vehicle insulation thickness decreases cooling power requirement by about 10% and heating by about 18%.
- The less time the vehicle has between stops, the more power is consumed due to the average cabin air exchange rate.
- Guide way vehicle shading can reduce overall power by about 27%.
- Power requirements are reduced with an increase of average levels of vehicle occupancy.
- Thermal management, such as proper insulation and shading, can reduce annual energy by about 26.8%.
- Average energy per mile per day (kWh/mile/day) for a linear induction motor based ATN various from 1600 – 250.

Using traffic count data collected by US DOT for every major highway, Ron Swenson and Robert Baertsch in their paper "Solar-Powered Personal Rapid Transit (PRT): Electric Vehicles without Batteries or Congestion", estimate an average traffic pattern that would be required to power a one-mile section of guide way. Their results estimate 2440 kWh/mile/day (Baertsch & Swenson, 2010) To verify their results, the solar SuperTeam in collaboration with the propulsion SuperTeam used energy equations developed by the leading expert on ATN's J. Edward Anderson in his paper "What Determines Transit Energy Use?". . The following equations were used to estimate the power requirements on a basis of energy per passenger mile (kWh/passenger*mile):

The electrical energy required per passenger mile is given by

$$\frac{E}{pm} = E_k + E_a + E_r + E_x \qquad (1)$$

where the kinetic energy component is

$$E_k = \frac{1}{\sigma_p} \left(\frac{W_p V_L^2}{2D_s}\right) \qquad (2)$$

the air drag component is

$$E_a = \frac{1}{\sigma_p}\{AD_p[V_L^2(1-1.5k) + V_w^2(1-k)]\} \qquad (3)$$

the road resistance component is

$$E_r = \frac{1}{\sigma_p}\left\{W_p\left[a(1-k) + bV_2\left(1-\frac{4}{3}k\right)\right]\right\} \qquad (4)$$

the auxiliary energy component is

$$E_x = \frac{P_{aux}}{V_{av}P_v} \qquad (5)$$

Table 1. Propulsion Design Specificationsgives a description of the notations used in the equations.

Table 2: Notations, description, and source of value

Notation	Description	Value	Source / Note
a	road resistance coefficient	0.0003	Anderson (1988)
b	road resistance coefficients per unit of weight per unit of speed, s/m	0.0001	Anderson (1988)
A_f	frontal area of vehicle , m^2	2	Estimated from the SuperWay podcar dimensions given in Appendix B
A_m	maximum comfort acceleration , 0.25g , m/s^2	1.23	Anderson (1988)
AD_p	air drag per passenger at unit speed	0.1003	Anderson (1988) $\frac{\rho C_d A_f}{2P_v}$
C_d	vehicle drag coefficient	0.13	Anderson (1988)

D_s	distance between stops, meter	1609	One mile assumption
k	dimensionless constant	0.175	Anderson (1988) $\frac{V_L^2}{2A_m D_s}$
P_{aux}	auxiliary power, watt	3700	Paige (2012), based on HVAC peak power demand
P_v	daily average number of passengers per vehicle	1.55	United States Department of Energy (2012), based on the average vehicle occupancy of a car
t_d	average time vehicle dwells at a station , second	30	Assumption
t^*	time, second	82.5	Anderson (1988) $\frac{D_s}{V_{av}} - t_d$
V_L	line speed, m/s	26.3	Anderson (1988) $\frac{1}{2}A_m t^* \left[1 - \sqrt{1 - \frac{4D_s}{A_m t^{*2}}}\right]$
V_{av}	average speed , m/s	14.3 (32 mph)	United States Department of Energy (2012), based on the U.S. daily average vehicle speed
V_w	wind speed , m/s	2.9	California Climate Data Archive (2009) , based from the annual average wind speed from the San Jose International Airport weather station
W	gross weight of vehicle , kg	1725	Assumption
W_p	gross vehicle weight per passenger , W/Pv, kg/pass/vehicle	1113	Anderson (1988) $\frac{W}{P_v}$

ρ	air density at 21°C, kg/m^3	1.196	
σ_p	propulsion efficiency	0.46	Shiri & Shoulaie (2012), based from a optimization theoretical model for a LIM
E_k	kinetic energy, Joules/passenger*meter	516	
E_a	air drag , Joules/passenger*meter	112	
E_r	road resistance, Joules/passenger*meter	6.001	
E_x	auxiliary energy, Joules/passenger*meter	167	
Total Energy	kWh/passenger*mile	0.358	
Total Energy Requirement	**kWh/mile/day**	**9619**	U.S. Census Bureau (2010) for Santa Clara County , CA .

The total energy (kWh/passenger*mile) is calculated based on a vehicle making a one mile trip. To calculate the total energy requirement based on kWh/mile/day, the number of trips made by the daily average number of passengers per vehicle needs to be known. To determine the number of trips, the Solar SuperTeam approached this problem by determining the number of commuters that go to work using public transportation in Santa Clara County. This gives a rough estimate of people that would be willing to use the SuperWay. According to the U.S. Census Bureau (2012), for the Santa Clara County there are 26,876 commuters that fit the description. This value gives the total energy requirement of 9619 kWh/mile/day (**Error! Reference source not found.**). This high value is heavily influenced by, P_v , the daily average number of passengers per vehicle (for further analysis on this topic reference Paige (2012)). If P_v is increased to a value of 6 (assuming a van size vehicle), the total energy requirement drops to 2485 kWh/mile/day.

Table 3: Comparison of Energy Requirements Estimates per Mile of Guide way

	ATN Feasibility Evaluation Study	**Swenson & Baertsch**	**Solar SuperTeam**
kWh/mile/day	1600 - 250	2440	2485

To size the SuperWay solar power system either the Swenson's and Baertsch's or the Solar SuperTeam's estimate can be used. Both estimates are maximum energy requirements and choosing either one ensures that the solar power system is not undersized. The Solar SuperTeam decided to use the Swenson and Baertsch estimate for preliminary SAM simulations discussed in the Solar subsection of Chapter 9: Preliminary Design.

Control Systems

Centralized Control (Synchronous)

One master controller determines the state and choreographs the entire system.

Description

With a centralized architecture, one heavily integrated system performs all command and control functions. In this environment, all mechanisms are simple extensions of the controller, functioning as input/output devices to the central “brain”.

Benefits

Centralized control has the capability to provide a global view of the system as a whole. These systems are architecturally less complex to build, design, and debug. With a focus on one highly integrated system, the architects and programs are only required to create one code-base with a single end-goal. Since every unit functions as an I/O device from the central control’s perspective, there is only a single communications stack which must be scheduled. This creates a single fundamental problem to focus upon with only one set of partitioning. Further, the approach to such a problem is well known and much has been written about said development.

With minimal intelligence in the pods, they will generate the least expensive pod-control electronics. Even in this case, there would need to be some communicating circuitry which communicates with the master control and deal with its commands, but that circuitry could be as simplistic as a state machine, polling the master for its next directive.

With one system in control of the entire network, finding and diagnosing the state of the world is feasible and should suffer under no communications lag. The failure state of every device is easy to determine (shut down and stop moving), allowing central control to react to a problem with complete knowledge of the state of the world.

Flaws

The world has been leaving behind fully centralized systems over the past 30 years for several reasons. Central control systems do not scale well. At some level of complexity, the simple scheduling of directives to each node overwhelms even the most robust system’s ability to communicate. Though such a system generates the least expensive pod costs, it generally nets the most expensive control system. In short, a centralized control system is more suitable for a small and simple transportation network (Berger 2011).

Analysis
In its purist form, a centralized system would be a disaster. Without intelligence in the car, every motion must be controlled from the central system. Predictably, as the system grows in size and complexity, the abilities of the master control must increase. At some point, the absolute limit in technology will occur, placing an upper bound on the complexity and size of this system. More despairingly, long before this limit occurs, the system will begin exhibiting inconsistent behavior as times of high demand receive a lower quality of service than times of low demand.

Reliability is explicitly not a concern with a central system. Though, at casual glance, there appears to be a single point of failure; there is no reason the central system cannot be built with many levels of redundancy (indeed where lives hang in the balance, three levels of redundancy are the minimum acceptable).

Examples
The Morgantown Personal Rapid Transit System can be taken as an example of a centralized PRT control system. This PRT system is centrally controlled with a combination of humans and automation making all decisions for the system. Since 1970s, Morgantown PRT system has shuttled 19,000 students and 7500 employees between campuses at West Virginia University (Gibson 2002). Morgantown PRT system has a record of uptime availability up to 98% with very few break downs, and in most, breakdowns were caused by mechanical problem from the vehicle (Albert 1983). Looking at a complex control system with the lack of technology from the 70s, Morgantown has demonstrated great reliability of its system. Another aspect to be considered is that Morgantown PRT only services five stops with an 8.65 mile total distance (Booth 2007). This is a relatively small model to be a good demonstration for a centralized PRT control system. However, as of 2010, Morgantown was still the only one of its kind.

Peer-to-Peer Control (Asynchronous)

Each unit within the system (pod, kiosk, etc.) is its own autonomous unit. The control is distributed across the entire unit-verse.

Description
In a peer to peer system, there is no true hierarchy amongst the systems, and every system contains the information necessary for its own autonomous operation. The units have localized intelligence sufficient for complete autonomous control. System level decisions are made by a voting or prioritization process which occurs through intra-node communication and some type of decision making tree (frequently an expert system of some type). One node communicates to the network when service is required which it cannot provide (such as a station requesting a pod), and through the same prioritization rules, some or many other systems answer.

Benefits
With each unit having significant intelligence, there is infinite scalability in processing power. Adding a unit increases the net capabilities of the system linearly.

Such systems have intrinsic fault tolerance. Since each unit is responsible for itself and for reacting to its operating environment, a failure in one place will be naturally worked around by those systems within the failing unit's operational sphere.

Flaws

As the number of systems increase, the raw complexity of the system and potential requirements for intra-node communication increases through the factorial of the number of nodes. This necessitates communications networks with ever increasing size or a willingness to partition the system into localized domains. Once a system is partitioned into localized domains, cross domain boundary handling becomes a significant problem.

Collating the state of the entire system into one view becomes an incredibly heavy process, made more difficult with partitioning. Due to communications delays, it is possible, nay likely, that a complete view of the system is never able to complete before the state of the system changes.

Since every unit must be able to autonomously function within its operational sphere and handle possible failure states with units outside of its control, the individual pod control system becomes rather complicated.

Predictably, a fully distributed system creates the most expensive pod controls, and necessitates a very robust communications network.

Analysis

Without some central authority to arbitrate between systems and to coordinate reactions to failure, a purely peer to peer system will be incredibly complex to implement. Further, the math governing the growth in necessary communications as the system scales creates an almost insurmountable scaling problem. One merely needs to look at the history of AppleTalk to see the communications trouble as the need for state communications increases.

Examples

The current automotive transit system works in this way, with rather complex humans functioning as the in car control system and a combination of traffic laws and the ubiquitous middle finger as the rules governing each units function and reaction.

The Hybrid Architecture (Quasi-Synchronous)

Description

The hybrid system would incorporate the benefits from peer-to-peer and centralized control systems. The system would inherit the central authority and maintain a certain level of world awareness on the nodes of the system. The authority will be able to coordinate between other external systems, such as ticketing with routing capabilities. The pods will have enough intelligence to be aware of the world and safely follow the routed path passed down by the authority.

Benefits
The authority, or master controller, will be able to make high level decisions for improved efficiency of the overall system and the pod intelligence will distribute fault tolerance across the system in cases of crisis. The efficiency gained from the authority will allow better traffic flow for faster travel times. The pod intelligence will allow any safety related events to be handled directly with the least latency and the most independence of other systems.

For any form of transit, safety is the most important consideration when designing control systems. During the event of a catastrophic failure, the system must support the means of safely returning passengers to the nearest station. The peer to peer network between pods will enable any operational pods to safely return to a station without the need to communicate back to the master controller. In the event the master controller fails or long range communication is down, the close proximity of communication in the peer to peer network will have a much greater chance of being operational since each pod will have its own intelligence.

Flaws
Since the system incorporates a hybrid of design structure, the system is expected to be more complex to implement. The complexity comes from having more components and subsystems to design.

Analysis
While the system will be difficult to implement, the safety gained will tremendously help adoption rate. The fault tolerance would be much greater, and still enable having a central authority to maintain a hierarchy in the system. In the case of half the system being taken down, the pods will still be able to make it to safety.

Chapter 7: Technology Selection

Cabin

Material Selection

The cabin frame will be made of 4130 Chro-Moly Steel. This material is an excellent candidate for this purpose due to its high strength to weight ratio compared to steel. Due to this ratio, this material is commonly used in airplane fuselages, race car roll cages and bicycle frames. It can be TIG-welded to construct the frame of the cabin. (Metal of the Month: Chromoly)

The exterior panels of the cabin will be made of ABS (SP-6710) panels, which is manufactured by Spartech. This material was chosen because of its light weight, protective UV coating and rigidity that provides high impact resistance. Other material that was looked at for consideration was aluminum, carbon fiber and standard ABS. UV coating is particularly important because ABS is susceptible to corrosion from sunlight. An outer aluminum body would be less expensive than ABS, still be lightweight, and builds a natural oxidation barrier against the environment but is not as impact resistant. In addition, since this system will be suspended, fatigue failure and the potential for crack initiation and growth that can result from these types of stresses are harder to anticipate and located since aluminum has no definitive endurance limit. (Norton, 2011) Carbon fiber reinforced fiber which exhibits an extremely high tensile strength ratio to weight ratio can withstand a high impact but it is expensive to manufacture. The material also lacks an endurance limit, so it would be hard to predict failure. In addition, due to the brittle nature of carbon fibers, the failure of a part would be sudden and catastrophic. (Kopeliovich, 2012) The ability of ABS to withstand impact is highly important in the event of a collision with in the system.

The interior paneling will also be constructed of ABS, more specifically Royalite R66. ABS is chosen for its low cost, easy maintenance and safety. (Spartech Royalite R66 PVC/Acrylic Fire Rated Sheet) This material is approved for use in automobiles because it passes Motor Vehicle Safety Standard 302 which specifies the burn resistance requirements for materials used in vehicle interiors. (U.S. Department of Transportation, 1999)

The seats will be upholstered with vinyl. Vinyl is inexpensive, but provides more comfort than more rigid plastic seats. In addition, vinyl fabrics can provide the same aesthetics of a more luxurious fabric, such as leather, while allowing for the easy maintenance (essentially wiping the seats) allowed by plastic. Interior seat materials, particularly for lining and seats, will most likely be fiberglass or phenolic-containing composite siding and fabrics. Such materials while fulfilling desired requirements, e.g. comfortable seats, but most importantly these materials are flame-retardant. (National Research Council, 1991)

The cabin will feature Polycast Super Abrasion Resistant (SAR) acrylic windows. This acrylic material is produced by coating an acrylic substrate with highly-cross-linked polysilicate. This combination is significantly harder than untreated acrylic while providing the same safety, optical, and aesthetic qualities. Most importantly, Polycast SAR is scratch resistant so the windows of the cabin will maintain optical clarity. The material provides an impact resistance that is five times that of glass for half of the weight and holds up to weather conditions, allows for easy cleaning, and provides heat insulation. (Spartech Corporation, 2009)

Propulsion

Linear induction motors are AC asynchronous motors that use the principles of induction to generate linear motion. Compared to rotary motors, linear induction motors operate over a finite length instead of an infinite loop. Linear induction motors operate by producing a moving magnetic field on any conductor, like aluminum, that is placed in the field, as seen in **Error! Reference source not found.**. The magnetic field generates eddy currents in the air gap, and the opposing fields result in the propulsion of the conductor. The field is controlled by electrifying the coils of the linear induction motor in series depending on the speed of the conductor. As the bogie travels faster, the LIM's will need to trigger the electric field more often. As a result, it will continue to consume more energy at higher speeds. Depending on the motor sizing and the amount of power given, the system will reach a top speed.

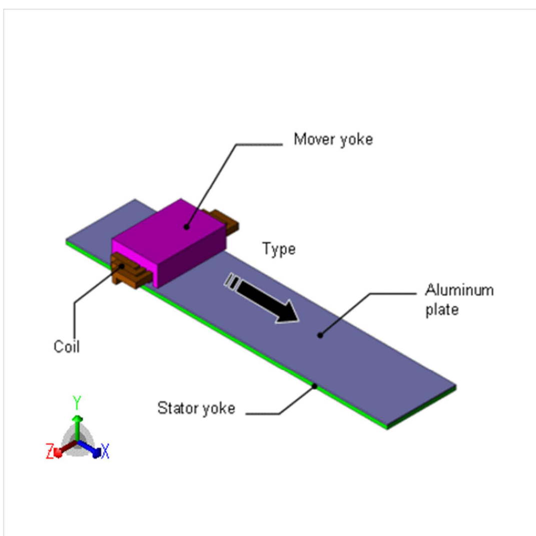


Figure 17: Fundamentals of Linear Induction Motors (Jmag-International)

In order to create prolonged thrust, either multiple motors throughout the track or dynamic motors are needed. The track for a typical single-sided LIM system is embedded with the motors (consisting of aluminum, control units, and copper coils). This allows for a lightweight cabin, since only a conductive, non-ferrous strip of metal is needed for propulsion. A lightweight cabin will require less energy to be propelled, but the track will be more expensive than a track without embedded motors. If the price per LIM is $8000, and they are spaced 15 feet apart, the track would cost an additional $3.5 million per mile. A dynamic motor also utilizes a single-sided LIM (SLIM) design (Gastli), but now has a short primary motor over a long secondary conductor, as seen in Figure 18: DLIM versus SLIM (Emsa.Gastli). This design allows for smooth acceleration and a more inexpensive track. However, it can lead to overheating if not treated properly. For example, if the motor is running but remains stationary, the motor's coils begin to overheat. Therefore, to increase the reliability and efficiency of the system, the track will carry the LIM's.

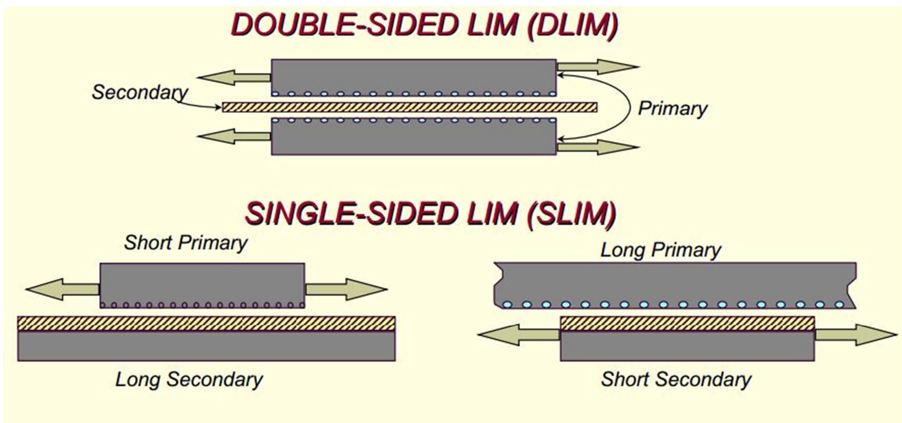


Figure 18: DLIM versus SLIM (Emsa.Gastli)

By placing the motors in the track, the system can take advantage of "location specific" track. Location specific track uses varying motor sizes depending on the force requirements of the specific section. For example, if the pod car was travelling up-hill, larger LIM's can be used to ensure the pod car reaches the top. This means that on flat surfaces, smaller, more energy efficient motors can be used to save energy and cost.

Linear induction motors have become more popular in recent years. Although the technology was designed in the 1970's, it has become more efficient over time with more advanced control systems. Linear induction motors offer several advantages over the traditional rotary propulsion systems. While rotary motors rely on the friction between wheels and the track for propulsion, linear induction motors utilize electric fields. The electric field allows LIM's to ignore any substance, like snow or ice, on the surface of the motor and produce continuous thrust without external slip. Using this method, LIM's can also act as a braking system by simply reversing the order that the motor coils trigger. While other systems have used the LIM's as the lone source for braking, mechanical braking, such as disk or drum brakes can also be used to assist slowing the vehicle. Using a mechanical braking system will also allow for regenerative braking. Regenerative braking has progressed to a point such that a system can recover nearly all of the power used for acceleration during braking, with as little as five percent loss.

Linear induction motors also have the capability to generate plenty of force. They can be seen in heavy applications, such as propelling roller coasters and launching aircraft. To calculate thrust (in Newtons), the synchronous velocity is divided by the air gap power (Gastli, n.d.). The air gap power is the product of the current input squared, and the resistance over the slip that occurs between the electric fields (Lu, n.d.). As previously discussed, the thrust produced will peak at an optimal synchronous velocity, and will severely drop if the synchronous velocity continues to rise. When this occurs, the conductor is moving faster relative to the movement of the electric field. Another advantage is the low maintenance requirements of the LIM system. Certain types of rotary electric motors use parts such as brushes or bearing to function, and gearing to achieve torque. These are all parts that will wear down over time. The design of the LIM has no moving parts and no permanent magnets and therefore requires less maintenance (Desantis, n.d). With few moving parts, this motor will also have a quiet operation compared to other electric motor designs.

Apart from linear induction motors, electric motors with a rotary design and magnetic levitation were considered. Rotary motors are very similar to electric cars. They consist of an electric motor, typically connected to the wheels through gearing. This type of system has been around for years and has proven to be reliable, but with several flaws. The PRT systems today that use rotary motors generally have a low cruising speed. This is due to the capabilities of the motor or the interface to the track. PRT's do not carry transmissions in order to save weight and maintenance costs. Therefore, the faster the PRT travels, the higher the RPM of the motor. This method generates more heat and consumes more energy. However, the major downside is the cost of these high speed motors. To gain some perspective, typical high power electric motors can cost around $10,000. Another reason current rotary PRT's travel at low speeds is because they run on rubber wheels guided by magnetic sensors on a concrete guide way (Transport). If a rail system was used, the rotary design would be more stable and could reach higher speeds. However, as the wheels are the only form of braking, steel wheels on a steel track would result in lower braking power.

Linear synchronous motors (LSM's) are similar to linear induction motors in implementation, but differ in the way they make thrust. Linear synchronous motors are typically the primary propulsion source when one refers to magnetic levitation. LSM's consist of closely packed coils throughout the track that create a magnetic field (*Linear motor and its use in transportation, 2011*). The bogie, integrated with permanent magnets, reacts to these coils in either a repulsive or attractive force. While this method can be used as propulsion and levitation simultaneously, there are some drawbacks. LSM's are synchronous, meaning that the control of each coil must be precise in order to smoothly accelerate the bogie. Also, since the bogie is fully levitating, a simple on-board switching mechanism is difficult to achieve.

An alternative method of using magnetic levitation is to create eddy currents to produce drag, rather than a repulsive force as seen in LIM's. Skytran has developed a technology that is referred to as a magnetic screw. In this system, permanent magnets are wrapped around a nonconductive cylinder and placed in an aluminum pipe. When the cylinder is spun by an electric motor, the permanent magnets create an eddy current in the air gap that propels the vehicle forward. This system is highly efficient as it simply powers a small electric motor, and can be used to reverse and to provide braking. To create levitation, the same principle is used on the outer wings that react with aluminum channels to create lift. This technology is still new and has only been seen in small scale prototypes; therefore it cannot be verified to be efficient for a 4,000 pound pod car. Also, as a form of magnetic levitation, there is no simple solution to track switching.

Structure

The design team has decided a suspended ATN system as the concept for the Superway. It has also been decided that the Superway will be 100% solar powered. This will require finding space to accommodate the solar panels on the structure itself. One of the main reasons the Superway was chosen to be suspended and not supported was because of the lower visual impact the structure will have on its surroundings as the solar panels are place on top of it. A supported system would require a double vertical structure, one supporting the guideway and one more supporting the solar panels. On the other hand, the structure of a suspended system can accommodate the solar panels right on top of it without the need to add a secondary level structure.

In addition to the Superway being a suspended system, the design team has decided that the structure be as modular as possible so minor disturbance to the surroundings be made during the construction phase. Therefore, the system will be design so the individual pieces be prefabricated at one location then carried and assembled at the construction site. The foundation will utilize precast concrete piles except in sensitive areas where the pounding on the piles as they are driven into the soil would create too much disturbance. In that case an alternate solution would be to use cast-in-situ piles.

Solar

There are many different types of solar panels on the market today. To determine the proper type of solar panel that is needed to be used for the SMSSV system, many factors must be taken into account and, also, many assumptions must be made. A criteria was developed for solar cell selection:

1. Solar cell efficiency
2. Lifetime
3. Cost
4. Weight

SAM simulations were done on various solar cell technologies to see how much energy each would produce. This will give the Solar SuperTeam a good sense of how solar cell efficiency impacts energy production given ideal settings as mentioned in Solar Design System Specifications.

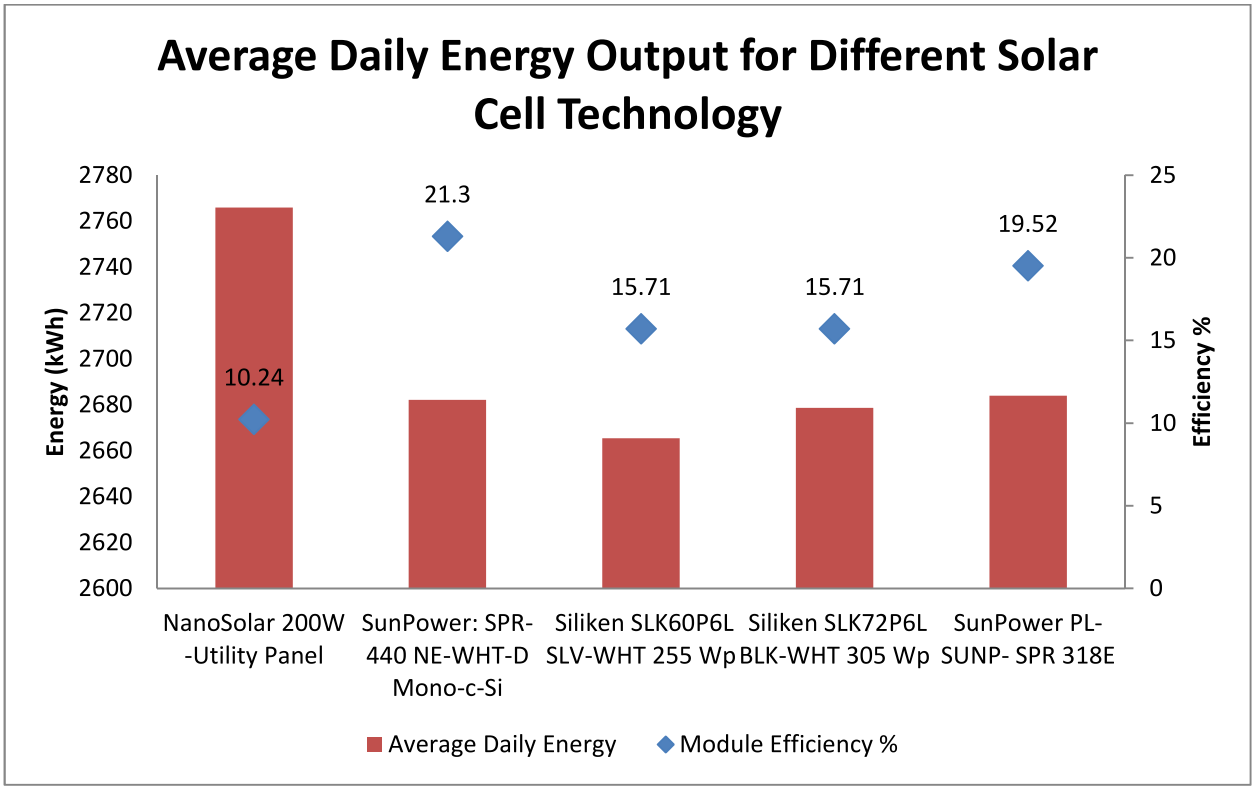


Figure 19: Various solar panels were chosen based on their module efficiency.

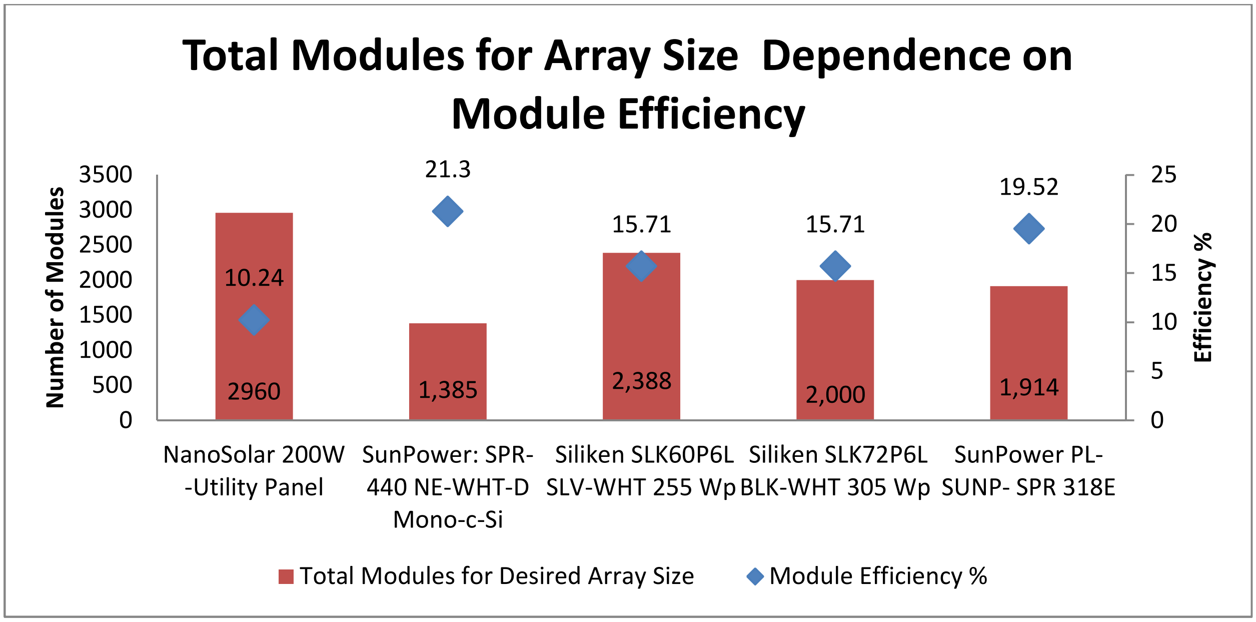


Figure 20: The greater the module efficiency the less total modules are needed for a given array size. The array size for the Figure 2 and 3 is 610 kW DC.

From Figure 19, above, the NanoSolar 200W-Utility panel produces the most energy, but from the following figure it requires the most panels. These two figures indicate that the Sunpower SPR-440NE-WHT-D panel requires fewer modules while generating about 200 kWh less than the NanoSolar panel. This amount of energy can easily be surpassed if the number of modules is increased, thus the Sunpower SPR panel would be a better selection to maximize energy production (due to the higher efficiency). The Sunpower SPR is thus the top choice for the SuperWay (this is the panel used for SAM simulations for Solar Design System Specifications). For further detail on module design specification see Appendix B. Ultimately, the most important factor will be cost, and trying to get the most efficient solar panel while still trying to keep it cost effective. Cost analysis will be considered in the next phase of the SuperWay project.

A promising solar cell technology is that of ALTA devices. The technology is in research and development stage, but the potential of their applicability is great (see Preliminary Design Concepts section). ALTA claims a solar cell efficiency of 30.8%, ultra light-weight and superior flexibility (Wang, 2013). Further analysis of this technology will be investigated and will also be a top choice for the SuperWay.

One of the most important design factors for the system was to determine if the vehicle cabin would be suspended or supported. It is important to know whether the system will be suspended or supported. Ultimately, the decision was made to have a suspended system. This is important because that factor will determine where and how much room there is for the solar panels to be placed. Based on preliminary designs the panels will be located above the guide way, similar to how panes are placed on rooftops of buildings. Logistically, it is much easier to place the panels with a suspended system than if the podcar was supported. Since space will be limited on the

PRT system, solar panel efficiency is highly emphasized. If there are two solar panels that meet the group's solar cell selection criteria, the more efficient panel will take up less space, and therefore will be the better choice. Another decision had to be made between mono-crystalline or poly-crystalline solar panels. Again, since space is a factor the group is going to be going with a mono-crystalline solar panel. Mono-crystalline are more efficient per area so this means that for the same amount of wattage the size of panel can be smaller.

A final factor that has to be considered is choosing tracking or stationary solar panels. Tracking panels will be able to produce more energy and will not have to be oriented toward the ideal due south. However, tracking panels cost more and it was determined the extra power from the tracking did not outweigh the cost difference from the stationary panels.

Chapter 8: Route and Urban Planning for the SMSSV System

Selecting Corridors: an Exercise in Transit Supportive Land Use Metrics

Introduction

Transportation infrastructure serves no purpose if it does not go to places where people live, work, play, or shop. However, how homes, shops, workplaces and places for leisure are distributed geographically and how densely they are arranged vary significantly in the existing landscapes of California cities. While some neighborhoods, such as Nob Hill and Chinatown in San Francisco, experience exceptional density of people, jobs and amenities, others relatively close by, such as those in Rohnert Park in Marin County, are significantly less dense.

Fixed guideways transit, like all fixed route / fixed infrastructure transit, cannot directly serve personal residences, and must be reached on foot or other traditional access/egress modes. The number of people who can access a specific stop is dependent on how many dwelling units or job units exist within the access area of the station. Because the variation in the way different varieties of fixed guide-ways transport operate, the density of jobs, housing units and shopping activities needed to provide the minimum number of people each station required to provide cost effective service can vary significantly.

The goal of the “transit supportive” land use metric based analysis is to use existing urban planning and sustainability concepts to establish a minimal threshold for the density of housing, jobs, shops or leisure space to support a fixed guide-ways system. This metric for minimal job/housing/leisure unit density is constructed from existing literature on sustainable supportive densities for fixed guide-ways transit. This metric is used in this chapter to identify and prioritize routes and corridors for development. For the intents of this project, ATN infrastructure support requirements will be considered comparable to those of existing light-rail systems in the US and Commonwealth nations. Job units per acre are assessed in this report using US Census bureau CES data.

Common measurements of land use suitability

There are several ways of measuring density and intensity of land use. Commonly, population density is used as the primary method of assessing the density of the land use pattern. However, using only population density is a misleading metric to measure the use. Population density calculations are based primarily on taking a census block, tract, or other census designated geography and dividing the census recorded population by the land area. This is represented in statistics of the number of persons per acre, hectare, or square mile. This statistic only gives accurate information on intensity of use for residential areas. Areas with significant non-residential uses, such as those with significant concentrations of employment lands, are underrepresented in their intensity of use and their importance as a trip generator.

There are a large number of less common, yet far more descriptive land use intensity metrics which capture facets of the built environment which the population density calculations do not factor in. To assess density of residential development, the accepted standard density metric is dwelling units per acre (Du/A). Dwelling units per acre is calculated using the number of units that are registered with a locality in a certain designated geography divided by the acreage of the area. Du/A calculations are standard in most zoning and general plan designations for residential zoning districts, where a proscriptive zone code is in force. (Other metrics are used for designated intensity zones under form based codes since no city in Santa Clara County operates under a form based code, they will not be discussed here). For example, under 20.30.200 et sec. of the San José Municipal code, the R-1 designated zones may only be developed to a density of 8 Du/A without a variance from code.

Employment lands are assessed for their density using a measure known as Job Units per Acre (Ju/A). Job unit per acre is a more complicated measure. Essentially, a job unit per acre indicates the number of supported jobs per acre. This calculation is often problematic and is sometimes undercut by large office buildings relying on large swaths of surface parking. These numbers are also more problematic as zoning defines permissible uses based on square footage, not the jobs per location. Most employers are not necessarily willing to divulge the total number of people on site. Publicly available data is most problematic with assessing Ju/A

Existing metrics for supportive land use

There exists a significant disagreement in the planning literature on what constitutes a “transit supportive” land use in terms of several measurements. Most metrics are based around population density, while some are based around the density of use, be it job units or dwelling units per acre. Each of the existing methodologies is discussed below

Newman and Kenworthy (2006)

Newman and Kenworthy, from Murdoch University in Australia, specialize in transportation sustainability research and as part of this research, developed a series of analysis whereby the energy use, distance traveled, and mode shift by the density of a developed area. In their 2006 article “Urban design to reduce automobile dependence,” they examined the transportation choice behavior in large Australian metropolitan areas.

In all Australian metropolitan areas, Newman and Kenworthy found that there exists a 'sweet spot' where the density of development coincided to an exponential decrease in automotive use and a significantly higher use of a public transit system. In conjunction, the energy use per capita followed the same exponential drop off to an asymptote as the decrease in automotive use (Newman & Kenworthy, 2006).

The point in their analysis where the major change away from auto dependence occurred was at an urban intensity of 35 persons or jobs, per hectare. In imperial units, this adjusts to around 15 persons or jobs per acre as a minimum threshold for a transit / alternative transportation land use density and intensity (Newman & Kenworthy, 2006).

Minimum Population Density	Minimum Du/A	Minimum Ju/A
35 per Hectare / 15 per acre	N/a	35 per Hectare / 15 per acre

Engel-Yan, Kennedy, Saiz, and Pressnail (2005)
Engel-Yan et al., from the University of Toronto postulate a much different approach for the supportive land use for sustainable transit use. In an analysis of various bay area communities, Engel-Yan et al. found that there was very little correlation between the intensity of land use and transit use. Rather, they found that the design of the streets within a development area dictated the mode choice behavior of residents. In terms of transportation supportive street designs and patterns, 'gridiron' or connective curvilinear street patterns were required if a location was to be to be supportive of transit. This behavioral difference is posited by Engel-Yan et al. to be due to the ability to walk to the locations from transit. Because the initial access and eventual egress, part of the trip must be made by bike or walk for any kind of traditional transit, (and indeed any non-traditional transit such as ATN/PRT) the resident must have a direct and connective grid of streets to use. 'Loop and Lollipop' type development extends the distances traversed to access facilities and thus does not make any such development, no matter how dense, suitable for a transit service (Engel-yan, Joshua, Saiz, & Pressnail, 2001).

Minimum Population Density	Minimum Du/A	Minimum Ju/A
N/a	N/a	N/a

Special considerations: Street layout, design, and connectivity.

Gordon and Vipond (2005)
Gordon and Vipond examined supportive land uses in the context of new urbanist development patterns. They examined the variation in planning approaches and density in traditional development patterns and new urbanist developments in suburban development areas in Markham Ontario, an edge cluster development at the edge of the greater Toronto area.

In their examinations of gross densities, Markham and Vipond found that the ‘new urbanist’[1] communities had both a greater density and a greater suitability for transit operations. In these

[1] ‘New urbanist’ indicates a type of neighborhood design that is promoted by the Congress for the New Urbanism. It is generally a type of neighborhood design with higher density and pedestrian focus.

Congress of New Urbanism (CNU) inspired developments, the densities for population and gross population density were up to three quarters higher than conventional development practices. In the Ontario case study, the supportive New Urbanist communities had a density of 8 Du/A and a population density of around 25 persons per acre (Gordon & Vipond, 2005).

Gordon and Vipond expand on the standards set down by the CNU, stating that the development studied, while dense does not meet the minimum CNU standards for fixed guide-way transportation, which is defined as 9 to 14 Du/A. While Gordon and Vipond express that the trends in new urbanist development are progressing towards sustainability, they feel that the 9 to 14 Du/A standard is a bare minimum for supportive density for fixed guide-way transportation.

Minimum Population Density	**Minimum Du/A**	**Minimum Ju/A**
N/a	9 to 14	9 to 14

Special considerations: No special considerations

Federal Transit Administration New Starts Program (USDOT)

In 1992, the first major multimodal transportation bill (ISTEA) created the New Starts program which was designed to provide funding to new major transit infrastructure investments. While these grants are usually issued to rail transit projects, they are available for most non-automotive motorized transportation projects. Unlike previous grant programs, New Starts required tie-ins with land use and regional planning as they connect with the transportation project. As a result, all projects which receive money through the federal New Starts program are required to submit a report on the land uses in the vicinity of a project to see if the land use can support the proposed project. The FTA, in reviewing their reports rates the suitability and gives it a supportive land use score (Federal Transit Administration, 1998).

This score is based off of 11 land use category ratings, rated on a low to high scale, much like a Likart scale. The six criteria are Corridor Economic Conditions, Existing Zoning, Existing Station Area Development, Station Area Planning, Regional Growth Management, Urban Design Guidelines, Promotion and outreach, Parking Policies, Zoning Changes, TOD/Market Studies and Joint Development Planning. Under existing zoning, high ratings were given for areas of mixed use and developments of densities higher than 8 Du/A. Station areas were considered to be highly suitable when they are located close to existing major trip generators, were located in higher density areas, and had a walkable station area design with a mix of uses (Federal Transit Administration, 1998).

Minimum Population Density	**Minimum Du/A**	**Minimum Ju/A**
N/a	Higher than 8 Du/A	N/a

Special considerations:

- Must contain major trip generators
- Contain a mix of residential and employment uses.
- Overall citywide changes to zoning must be transit supportive
- Regions must be committed to curbing growth outside transit corridors
- Parking must be restricted
- Have ‘serious plans’ for implementation

Proposed Land Use Metric

No single metric using only unit density, population density or other metric can adequately assess the suitability of corridors for transit supportive use. As such, this project requires a flexible metric, which sets forth multiple conditions which would be considered suitable for the variety of land uses in Silicon Valley.

For the intents and purposes of this project, the planning team used a three-part land use assessment metric. One based on unit density, one based on population density with special conditions and one based on zones designated as TOD or transit village in general plans. If any area fulfills one of these metrics shall be considered suitable for fixed guide-way infrastructure deployment.

The unit density minimum is to be considered at 9 Du/A as it is barely above the FTA minimum and the lowest unit density under the work of Vipand and Gordon. Given the disperse development pattern of campus developments with ‘seas’ of parking, the higher employment densities should be considered at 10 Ju/A. Unit density is only indicative in situations where a connected road system exists to allow passengers to walk the final leg of their journey.

Minimum Residential Unit Density	**Minimum Employment Unit Density**
9 Du/A	10 Ju/A
Special Conditions: Connected road system	

If information on unit density is not available, an assessment based on population density should be considered. This metric would be based off of the Newman and Kenworthy metric of 35 persons per hectare. Again, this metric must come with the special conditions of a connected road system to allow for access and egress trips by foot or bike. The density would be based on census tract level measurements of population from the 2010 decennial census.

Minimum Population Density
35 persons per Hectare
Special Considerations: Connected Road System

If neither of these conditions exist, but the location has a zoning designation that is specifically transit supportive, it will be considered a supportive environment. Designations such as Transit Village, Urban Core, TOD or related designations are to be considered. The designations by locality are found below:

Table 3: Locality Designations

City Name	Appropriate Zoning Designation
San José	DC, DC-NT1 (SJC 20.70.100 et sec.)
Campbell	P-O, C-2, C-3 (CMC 21.10.010 et seq.)
Sunnyvale	C-1 through C-4 (SMC 19.20.030) Downtown Specific plan zonings (SMC 19.28.070)
Mountain View	PFD (Mountain View Code of Ordinances 36.20A) T (MVCO 36.22B et seq.)
Cupertino	CG, OA,OP, P, T (Cupertino MC 19.60.030 et seq.)
Palo Alto	CD (18.18.010 et seq.), MOR, ROLM, RP (18.20.010 et. Seq.)
Milpitas	MXD (Milpitas Municipal Code XI-10-6.01 et seq.), IZ (MMC XI-10.10.02 et. Seq.).

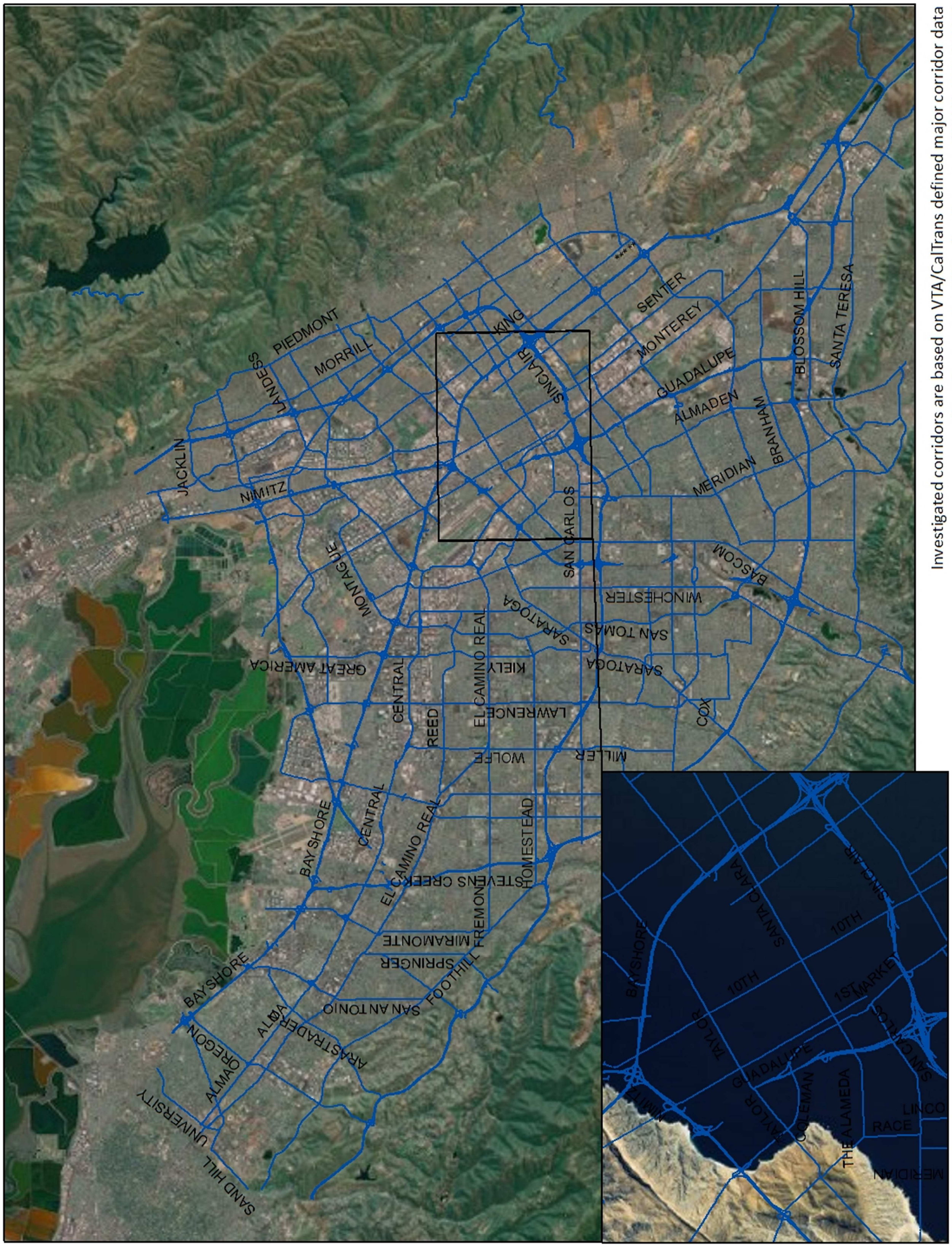
Corridors for Consideration

Why Major Roads?

As much as transit designers would like to believe that the guideways they have designed are the most beautiful and aesthetically pleasing things ever built, large pylons and structures are universally considered unsuitable for a neighborhood or residential settings within the urban planning world. Given the power of communities under land use law to litigate and persuade local authorities to not grant entitlements, it is likely that any system proposed to go into neighborhoods would be challenged and litigated for years postponing, possibly indefinitely, any implementation. Therefore, for the purposes of this analysis, only major arterials, freeways and collector roads are considered as suitable corridors, as well as existing transit rights of way where suitable clearances and width are available.

During geospatial analysis, the planning team used corridors defined by the localities, the VTA and the county of Santa Clara as major arterial roads, freeways, expressways or collector streets. These corridors are the roads, expressways, and highways which would have a sufficient cross-section to handle an overhead guide-way built above it. These corridors are seen in the map in **Planning Map 1**.

Planning Map 1: Investigated Corridors



Investigated corridors are based on VTA/CalTrans defined major corridor data
Data Sources: ArcGIS online Basemap (2012); VTA (2010)

Figure 21: Planning Map 1

Which Corridors have the most sportive land uses?

To find supportive land use, the analysis was conducted using an overlay of the three different types of data: population density, job density and zoning designation by area or parcel.

- Population data was derived from SF-1 2010 decennial census data from the US census bureau (United States Census Bureau, 2011). This was analyzed at the census tract level, which was the smallest geographic grain available. The population density was determined by dividing the population of each tract by its area in acres
- Job density is derived from Center for Economic Studies (CES) data from the US Census Bureau which contains total employment by census tract (United States Census Bureau, 2011). Density per acre was calculated dividing gross employment data by the area in acres of each census geography.
- Zoning designations supportive of fixed guide-way transportation is based off of the zonings highlighted in the land use metric. Zoning data was acquired from the cities of San José, Mountain View, Milpitas, Sunnyvale and Santa Clara. Data was requested from Palo Alto, Cupertino, Los Gatos, and Campbell, but no data was provided by the cities for this project.

These three data types were overlaid on a map of the corridors to show which corridors are proximate to the suitable land uses shown in green. This is shown on the following page in **Planning Map 2**.

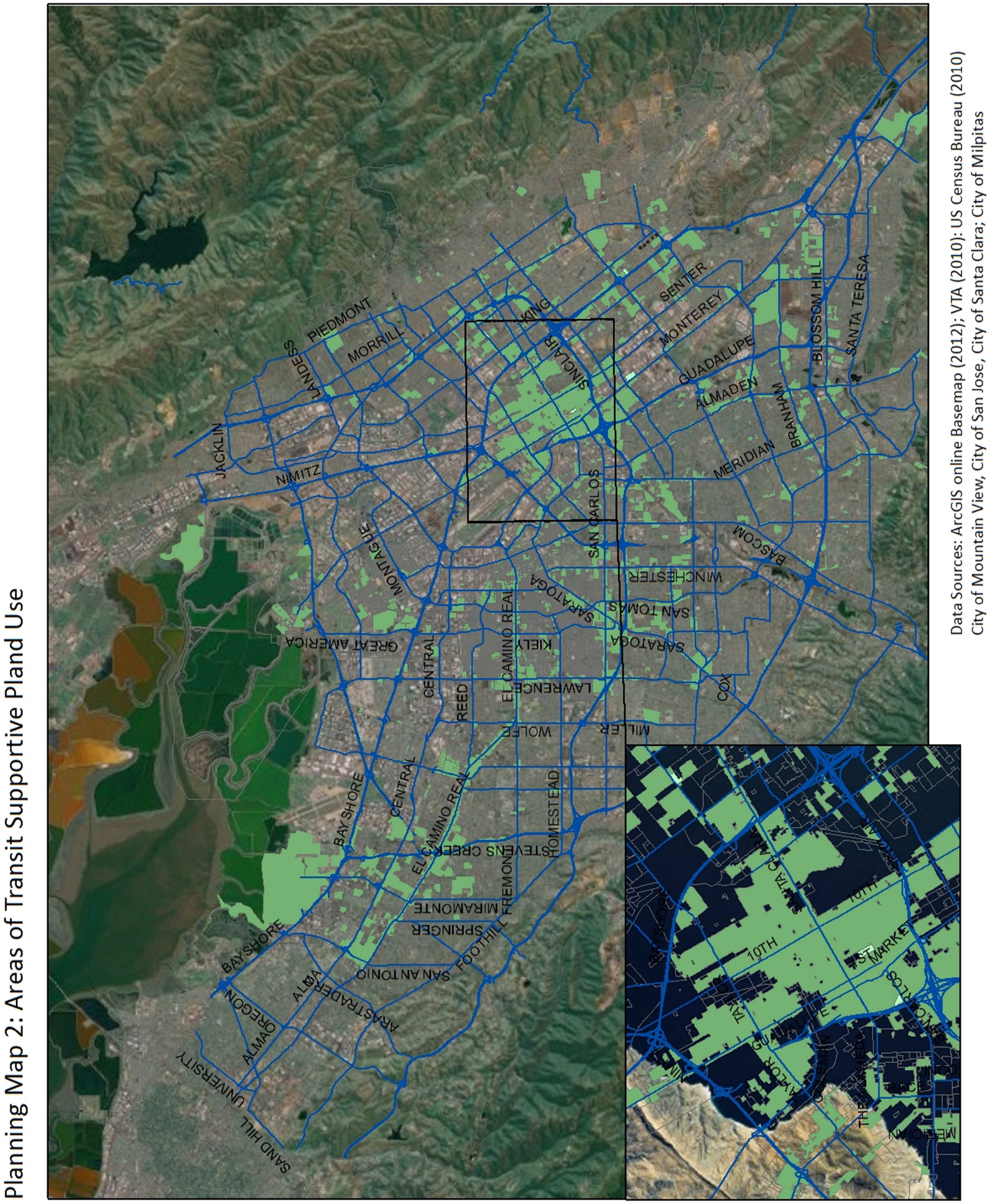


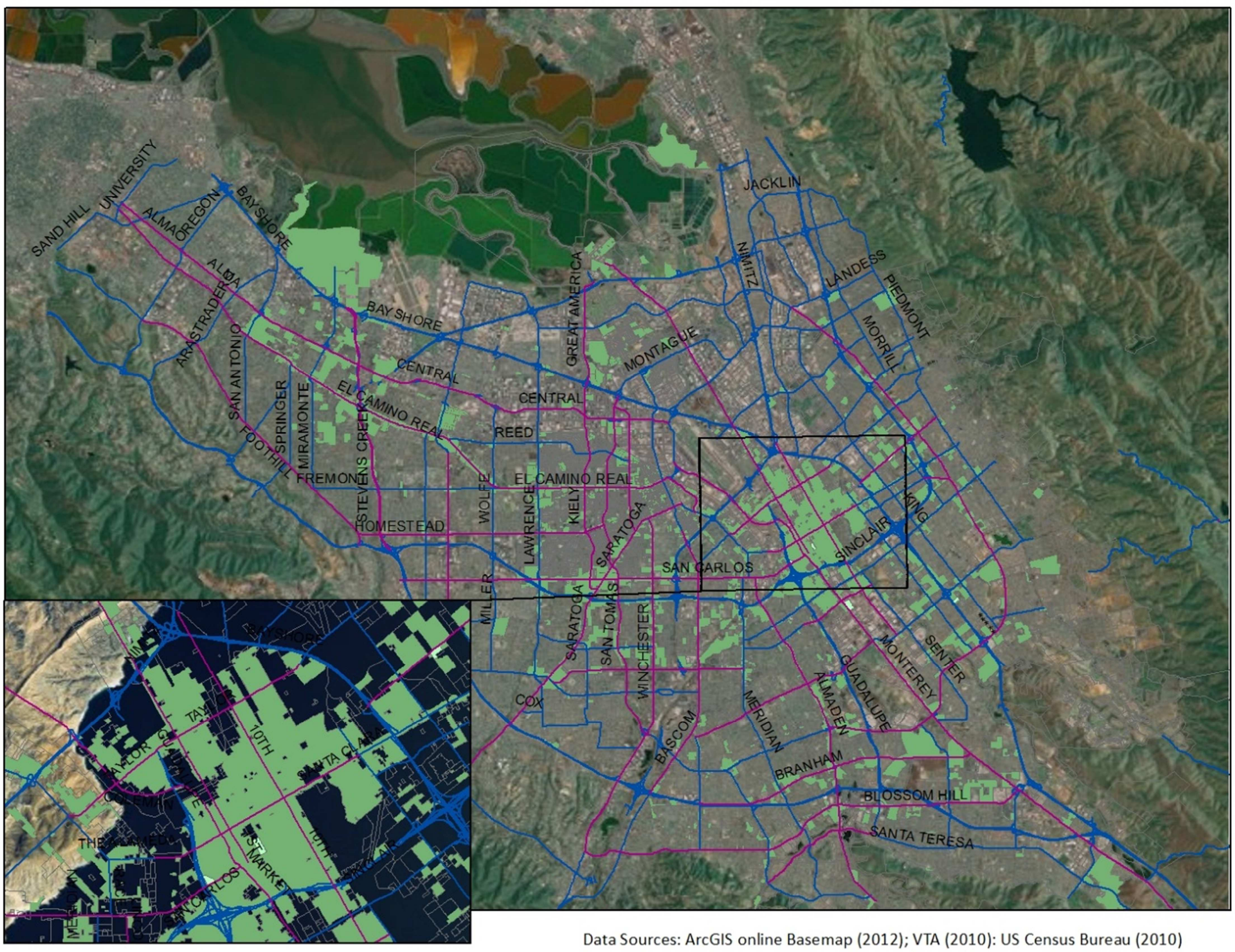
Figure 22: Planning Map 2

Most major corridors contain some small smatterings of some supportive uses, while very few corridors have supportive land uses along their entire path. Of the corridors observed, the corridors shown in purple on Planning Map 3 are those which were adjacent to the largest number of transit supportive land uses. Freeways were avoided as much as possible as locating the infrastructure in an accessible way along them is considered to be problematic, at least in Phase 1.

Proposed Initial Corridors

Once the most suitable corridors had been found, an initial set of sub corridors had to be selected

Planning Map 3: Suitable Corridors



Data Sources: ArcGIS online Basemap (2012); VTA (2010): US Census Bureau (2010)
City of Mountain View, City of San Jose, City of Santa Clara; City of Milpitas

Figure 23: Planning Map 3

for an initial operating network. The planning team, using the transit supportive land use areas as well as knowledge of existing patterns of movement highlighted the corridors found in yellow on **Planning Map 4.**

The selected corridors are primarily focused on serving Mountain View and San José central cores while also serving primary and secondary urban and development cores in Santa Clara and Sunnyvale. This pattern attempts to serve a significant portion of the central core urbanized settlements with the use of a minimum number of corridors. The initial corridors were also designed in a way as to connect as closely as possible with existing transit services and not overly duplicate any other major rail corridor in the county.

Further study is required to see if changes are necessary when the planned future land uses alter which corridors have the highest concentration of transit supportive land uses.

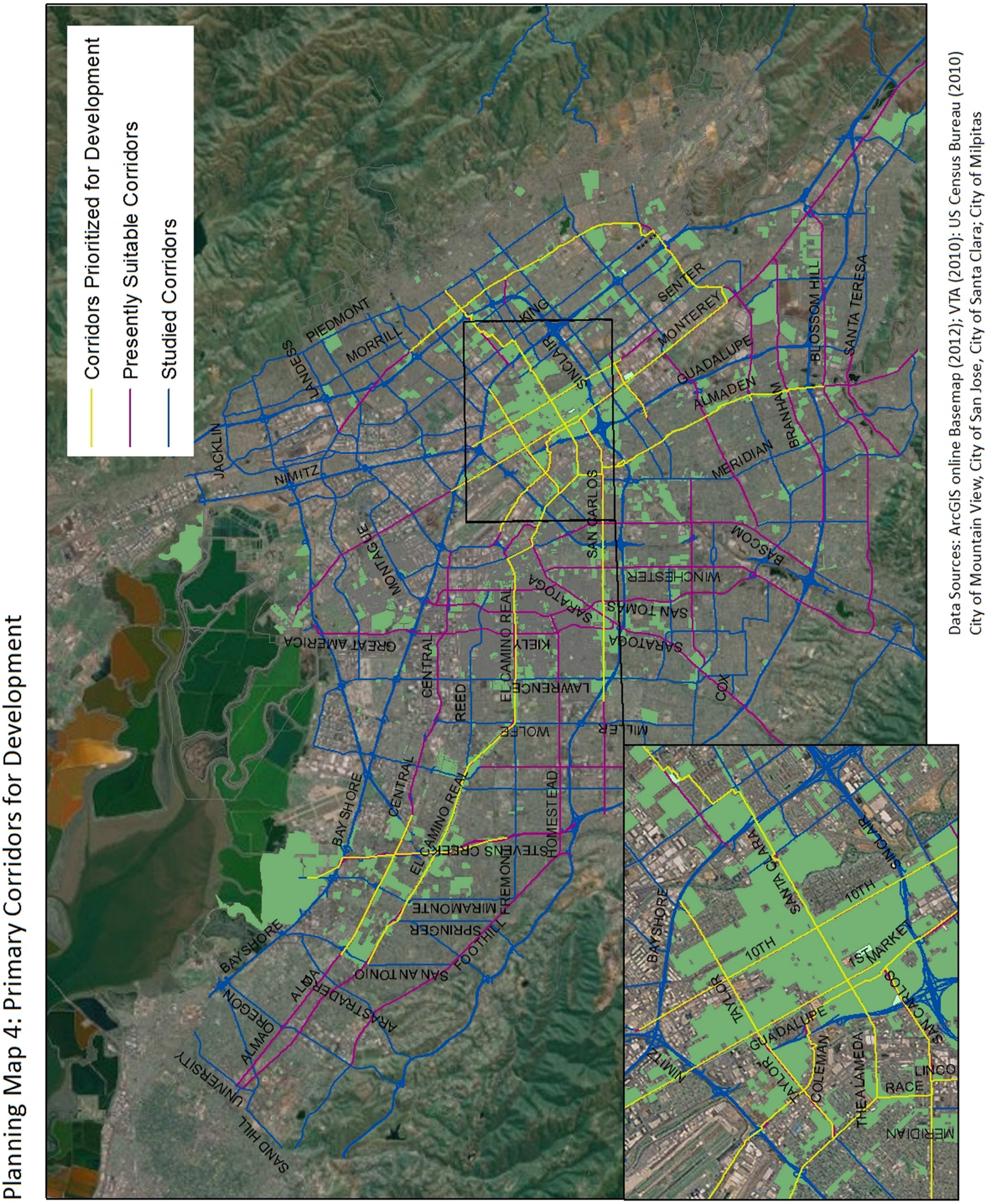


Figure 24: Planning Map 4

Future Steps

Now that the initial corridors have been selected for the initial roll out of ATN infrastructure, further study is required on several facets of planning and ATN network. The following tasks constitute the next steps required to transition from project level planning to planning for specific corridors to the next phase of the project.

- Approach localities along the corridors to examine what level of encroachment permitting is possible along existing city owned street rights of way for elevated ATN infrastructure.
- Corridor level assessment of existing conditions and opportunities for infrastructure development
    - Assess likely station locations
    - Assess the level of encroachment permitting required at station locations.
    - Create station and corridor specific plans that take into account existing and planned land uses and zoning
- Create context sensitive solutions for each corridor proposed for development
- Create a public scoping and outreach plan to bolster public support for ATN on each corridor.

The Land Use Entitlements and Environmental Review Process: A Overview for ATN

The Land Use Entitlements Process

Gaining Land Use Entitlements for Constructions: A Roadmap

The planning process, like any bureaucratic process, takes a long time to go from the initial proposal to the final grants of entitlements required to start construction. It exists primarily to ensure that the approval of any project by a public agency is undertaken with the wishes of the community and in a way that all people who are impacted have the ability to weigh in on a scheme (Levy, 2011, pp. 1-4). The modern planning process is the result of decades of abuses of the public processes that led to the government dictating projects, such as freeways and redevelopment projects, which had no local support and actively damaged communities (The International City/County Management Association, 1988, pp. 33-47). While the process may not make much sense for the uninitiated, it exists in a way to preserve the rights and properties of anyone affected so a just and presumably equitable solution can be constructed.

The planning process in California is defined like any other governmental process in the state by the California Governmental Code, though the exact process varies slightly from locality to locality (Talbert-Barclay, 2011, pp. 517-519). There remains the constant that the process is undertaken in full view of the public and that all that are affected shall have their say. Whatever permutation of the process is applicable for the SuperWay Project in its final form, it will have to be followed exactly to achieve a defensible set of building entitlements and permitting.

A beginner's guide flow chart is presented below (Governer's Office of Planning and Rearch, 2001) (Buys, 2005):

- **Initial Application**
  - A prepared application with plans and designs are submitted with application fees to the responsable agency.
- **Design Review**
  - The prepared proposal is analysed by staff to see if it is compliant with the local codes and statewide building codes. If the project fails in this step, the project returns to the begining of the process.
- **Final Application**
  - The appliction, once it has passed design review, is finally entered as a formal project for consideration and permiting.
- **Environmental Review**
  - An explination of the process is to be found in a further section
- **Public Outreach**
  - Information concerning the project and its impacts to the effected communities is presented to the community, who then the recieve time to comment.
- **Project Analysis Process**
  - The staff of the repondsb;r agency conducts an analysis and prepares a reccomendation for the local authority board or council.
- **Entitlements Hearing**
  - A public meeting is held where a decision on granting entitlements is decided.
- **Legal Appeals**
  - After the granting of entitlements, any member of the public may litigate to overturn the decision on many different grounds, including insufficiancy of the environmental review and abuse of discretion.

Figure 25: The Land Use Entitlements Process (Simplified)

Police Powers and the Planning Process

Land use controls, planning, and zoning are all an outgrowth of a series of powers granted to local and state governments known as 'police powers.' Police powers, as interpreted in case law, are defined as the power of government "to protect the public health, safety, and welfare of its residents (Levy, 2011, p. 73)." The use of zoning and land use controls were first codified in the case of *Village of Euclid OH., V Ambler Realty Company*, and further established and expanded in *Penn Central Railway V. New York* and *Associated Home Builders, Inc. V. City of Livermore*, in the specific context of California (Talbert-Barclay, 2011, pp. 1-4). The basic premise of these cases establishes that there is a compelling public interest in keeping incompatible uses away from one another or preventing undue impact on existing communities. In the Euclid case, zoning was originally established to keep noxious industrial uses away from lands on which people would be domiciled. One common example given is separating the location of an animal rendering plant from a residential neighborhood.

Over time, these powers have been interpreted broadly to create a wide system of zoning and planning designed to keep incompatible land uses and facilities away from one another, and ensure access to light, air, and livable spaces. Incompatibility has been more broadly described to include impacts of noise, shadow, visual blight, traffic and other non-traditional noxious impacts on a community (Talbert-Barclay, 2011, pp. 1-4).

Sunshine, Public Input and the Entitlements Process.

The land use entitlements process, like all governmental processes vested in local authority in California, must be conducted in full view of the public in such a way that the public's input can be heard on any issue discussed. California is more open than most states and has some of the most stringent rules on public hearings to prevent decisions being made out of the public eye (Levy, 2011, pp. 95-96).

The open conduct of meetings, noticed in advance, and in accessible locations is dictated by the Ralph M Brown Act, which comprises §54950 to §54963 of the California Governmental Code (Talbert-Barclay, 2011, pp. 500-504). This act mandates the following requirements for public meetings in which decisions are made:

No members of the local authority body may discuss the decision for a project in which a quorum of the council is present, unless conducted in public.

Any meeting of a quorum of council members constitutes a meeting and must be made accessible to any member of the public with reasonable accommodation for any person who wants to attend.

Any violation of the Brown Act can expose the public body to being legally enjoined against their decision, as it may constitute an abuse of discretion.

Environmental Review Under CEQA

CEQA: A primer

The California Environmental Quality Act (CEQA) is one of the first environmental review laws introduced in any state. It's main purpose is to "inform governmental decision makers and the public about the potential significant environmental effects of proposed activities; identify ways that environmental damage can be avoided or significantly reduced; require changes in projects through the use of alternatives or mitigation measures when feasible; and disclose to the public the reasons why a project was approved if significant environmental effects are involved" (South Coast Air Quality Management District, 2011). CEQA became part of California law in 1970 and comprises California Public Resource Code §§21000-21177.

The environmental impact review process (EIR) varies depending on the level of impact created by any project. A project, as defined under CEQA, is any discretionary action carried out or approved by a public agency (Talbert-Barclay, 2011, p. 152). Some projects are exempted under the law and require no review. Those that are not exempt must undergo an initial study which examines the extent of the impact of a project (Talbert-Barclay, 2011, pp. 158-159). Depending on the severity of the project impacts various, methods for identifying and mitigating impacts range from a negative declaration if there is little impact to a full EIR in the case of significant impacts. The process in detail can be found in Figure 26.

A project of the size of an ATN system is likely to incur at least one major impact. Therefore, it is likely that any ATN system in California will require the EIR process. Given the large impact it will have on existing streets, it is imperative to mitigate impacts that might be caused by a full scale system.

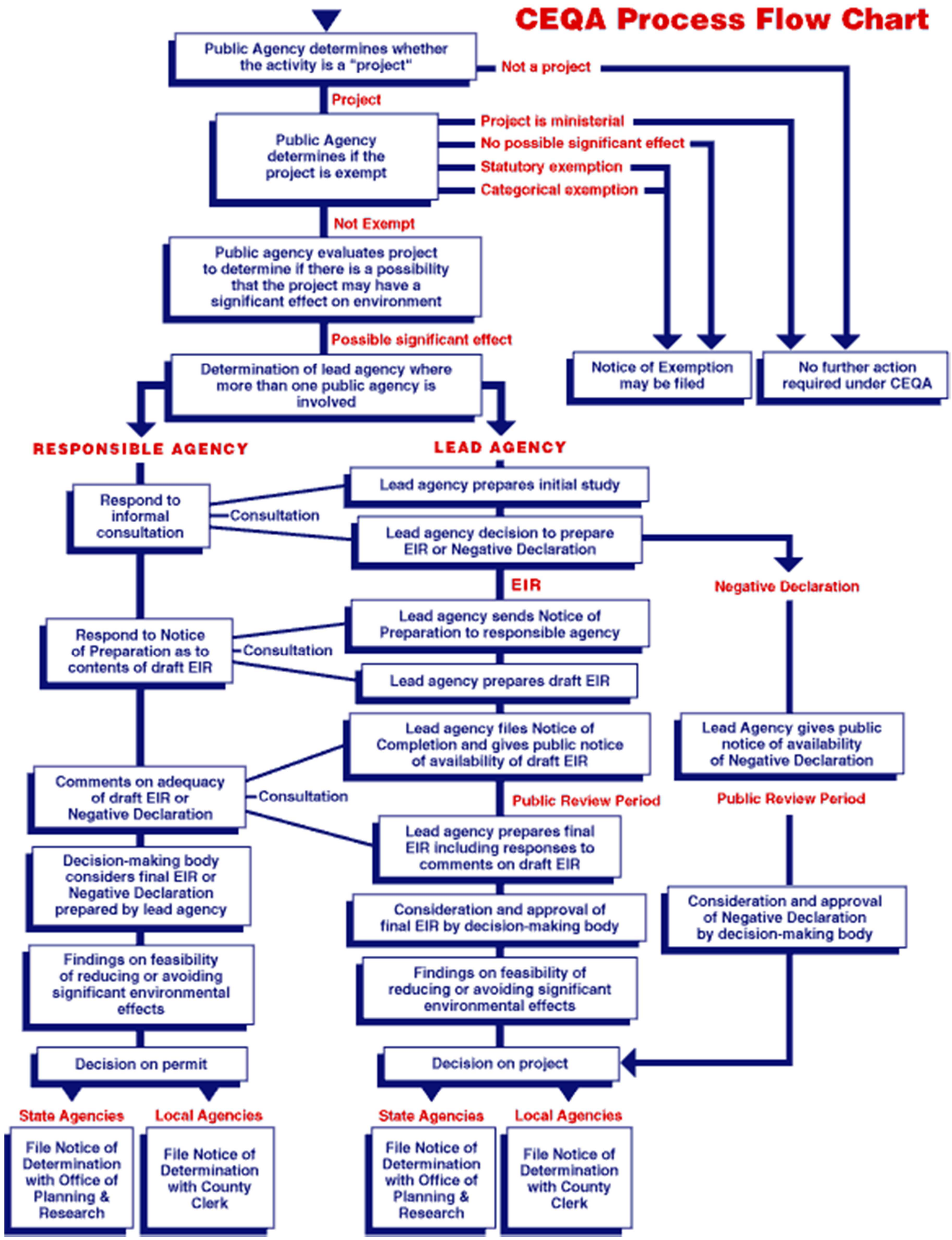


Figure 26 The CEQA Process (California Environmental Resources Evaluation System, 2005)

Defining the Lead Agency

The lead agency is the agency which

1). Overseas the environmental review process

2). Makes the final certification and approval of the Environmental Review documentation.

Depending on the scope of the project and the scope of the initial construction phase, the agency responsible varies (Talbert-Barclay, 2011, pp. 151-155).

- If a project stays within the bounds of a single city, the city council has the final vote over approving the Environmental Review or are able to devolve the power to an agency board. The lead agencies are usually the department of planning or department of transportation.
- In the case of Consolidated City/Counties the Board of Supervisors has the final authority and assigns staff oversight for transport projects to either a municipal or county department depending on departmental remit. In San Francisco, the Department of Planning oversees transportation projects, while final approval lies with either the San Francisco County Transportation Authority or the San Francisco Municipal Transportation Authority boards depending on project remit.
- In the case of a project that crosses city boundaries but not county boundaries, the certification of the environmental review is taken by the Board of Supervisors or the board of the county department with a transportation remit. Oversight of environmental review is undertaken by an assigned agency, usually the planning department or transportation authority.
- Where transportation projects are undertaken within a county transit district, the special authority board certifies the environmental review and is overseen by the transit agency staff.

Under CEQA, the actual permitting of the project can be done by the same agency as the lead agency or by a separate agency that functions as the responsible agency (Talbert-Barclay, 2011, pp. 151-155).

In the case of implementing an ATN system within Silicon Valley, it is likely that the initial system construction would be within the confines of the county of Santa Clara. Given the current set of planned roll out corridors, the project area will encompass multiple city jurisdictions. Given the geographic role out proposal, the agencies are defined as such:

- The responsible agency will be the Santa Clara Valley Transportation Authority, commonly known as the VTA (Santa Clara Valley Transit Authority, 2012) . While the VTA is known for its provision of transit service in Santa Clara County, it is also the agency that holds the remit over countywide transportation projects**. However, VTA does not retain the right to grant permits for an ATN project.**

- As the ability to grant permits rests solely with the local authority to grant the actual construction rights (Talbert-Barclay, 2011, pp. 1-5). Therefore, any locality in which ATN infrastructure is to be rolled out in shall be deemed to be a responsible agency.

The CEQA Checklist: Anticipated Worst Case Impacts

The CEQA checklist is a list of possible types of impacts that have to be investigated as part of the environmental review process. For the purposes of this analysis, it is assumed that the ATN project will have some impacts both in implementation areas and during the construction process. Assuming impacts similar to constructing other elevated structures either for transportation or other projects (Los Angeles County Metropolitain Transportation Authority, 2005) (Bay Area Regional Transportation District, 2006); the planning team assessed potential impacts and checked off impacts and levels of impact commensurate with the project, given the current state of design.

Of the 17 classifications of impacts in the checklist, the SuperWay ATN system is considered likely, under the analysis presented here, to trigger impacts in the following areas of study (California Environmental Resources Evaluation System, 2012):

- Aesthetics
    - Substantially damage scenic Resources (Less than Significant with mitigation)
    - Substantially degrading the existing visual character and quality of the site (Potentially Significant impact)
    - Create a new source of glare (Less than Significant with mitigation)
- Biological Resources
    - Conflict with any local policies or ordinances protecting biological resources such as tree protection policies (Potentially Significant impact)
- Noise
    - Exposure of persons to noise level in excess of standards (during construction) (Potentially Significant impact)
    - Exposure of persons to or generation of excessive ground borne vibration (during construction) (Potentially Significant impact)
    - A substantial temporary or periodic increase in ambient noise level in the project vicinity (during construction) (Potentially Significant impact)
- Land Use / Planning
    - Conflict with any applicable land use plan policy or regulation (Potentially Significant impact)
    - Physically divide a community (Less than Significant with mitigation)

- Transportation and Traffic
    - Conflict with adopted plans, policies or programs supporting alternative transportation (during construction) (Less than Significant with mitigation)

Given the number of impacts, and the number which could potentially trigger a significant impact, **it is likely that the project will require a full environmental documentation and approval process.** At present there exists no exemption for this kind of project in state law, and thus the process cannot be avoided. A full initial study will have to be compiled when the final proposal is completed to confirm that these worst case scenarios assumed impacts are the same as the actual impacts that the project will have on the community.

Operations Approval Process

Before any transportation system goes into operations carrying the general public, it must undergo a rigorous assessment and approval process at the state and federal levels. State and federal regulators exist primarily to ensure that any system that carries the general public operates safely and securely with appropriate safety and emergency protocols. Each level is covered below.

CTC, CPUC and Operational Approval

At the California State level, there are two bodies that define approvals over transportation projects in California. The California Transportation Commission (CTC) overseas the approval of all funding while the California Public Utilities Commission (CPUC) overseas the operation procedures and safety of operations within California (California Transportation Commission, 2011) (California Public Utilities Commission, 2012).

If an ATN system is to gain any funding from the state of California, it will have to go before the CTC for approval. To receive funding from the CTC, it must receive approval from the subcommittee for mass transit which usually requires that the operation be considered safe and operationally viable (California Transportation Commission, 2012). The CTC in general defers to the CPUC on matters of safe operations.

Before an ATN system can begin operations in California, it must gain approval like any other transit operation from the CPUC. The CPUC is tasked with the safety of all fixed guide-ways systems in the state of California (California Public Utilities Commission, 2011). All fixed guide-ways systems must operate according to safety rules incorporated into the CPUC general orders, which have progressed and evolved since the CPUC gained purview over rail safety (California Public Utilities Commission, 2012).

At present, the rules that the CPUC uses for safety preclude the certification of any ATN system as it focuses on designs specialized for light rail transit, automated people movers, and heavy rail. To gain authorization to operate ATN in California will require an amendment to existing general orders or a new general order from the CPUC specific to this mode. Given the speed with which the CPUC has taken in platform height reforms, it is likely that this process may take a significant period of time without the support of large cities or agencies.

Federal Approvals (if federal funding is acquired)
The federal government does not specifically oversee the authorization of operations unless those operations cross state lines. As the proposed system in this project does not leave the State of California, it does not have to contend with federal approval (United Stated Department of Transportation, 2012).

However, if an ATN system were to receive any federal funding, it would be bound by specific procurement rules. Under 49 U.S.C. § 5323(j) and 49 C.F.R. Part 661, all iron, steel, and manufactured products purchased with federal funds must be purchased from US domestic suppliers (United States Department of Transportation, 2012). Manufactured components include electronic components, and computer systems, although systems manufactured with foreign components but assembled in the United States is permitted (United States Department of Transportation, 2012). If no suitable indispensable component can be found that meets these criteria, a waver may be granted at the Discretion of the department of Transportation (United States Department of Transportation, 2012).

Next Steps for Planning

The land use entitlements and environmental review processes are currently not designed to easily accommodate the planning for ATN. While the environmental review process for transportation projects is appropriately suited for ATN infrastructure, the existing codes and plans which govern the construction and building of buildings and infrastructure are not. The land use process operates under the concept of "whatever is not permitted is prohibited," which means that unless there is a provision in code, at present it will require special enabling legislation at the city level to get a project built. Therefore the following next steps are indicated:

- Creating a model zoning ordinance amendment to introduce ATN infrastructure as a principally permitted use in roadway corridors
- Create a model zoning ordinance amendment to introduce specialized encroachment permitting for stations on the main right of way.
- Examine methods for accessing state and federal funding dedicated to transportation innovations.
- Propose ATN specific safety and operation regulations for federal and state regulatory bodies
- Conduct a more rigorous assessment of environmental impacts based on final routes and technology designs.

Chapter 9: Networks

Introduction

In the simplest terms, a network is a group of objects that are connected to one another. A network may be represented visually as a geometric figure with points and lines (respectively called nodes and edges in technical language).

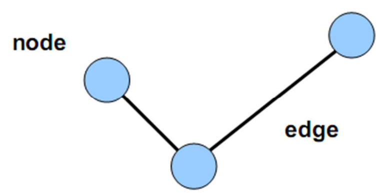


Figure 27: An example of a simple network consisting of three nodes (points) and two edges (lines) connected in a linear fashion.

Our world is abundant in networks of all kinds. Examples include ecological networks of biological organisms, neural networks in our brains, and communication networks such as the internet. But real-world systems are often complex and difficult to decipher. By reducing systems to their most elementary components, networks provide abstract representations that help facilitate human interpretation. Generally speaking, networks may be observed from three different levels:

- Individual entities within a group
- Relationships among connected individuals
- Patterns of interactions across a system

Each of these aspects both inform and are influenced by a network's structure and behavior. To better illustrate this point, consider a social network. A person might be naturally inclined to surround himself with people whose interests and preferences are similar to his own. But as relationships evolve and friends are made and lost over time, those changes are likely to shape an individual's personality and behavior to a significant degree. Human social interactions are undoubtedly complicated and dynamic systems—not unlike transit networks in many ways.

Motivation

A transportation system, the personal rapid transit (PRT) in particular, exhibits many features of an idealized network. Any transit network generally consists of pathways (edges) along which people/vehicles travel leading to various destinations (nodes) across a geographic area. In the case of an automated transit network (ATN) such as the PRT, humans driving through crowded and chaotic streets are substituted for computer operated podcars propelled along fixed guideways. The result is a system vastly more organized and predictable.

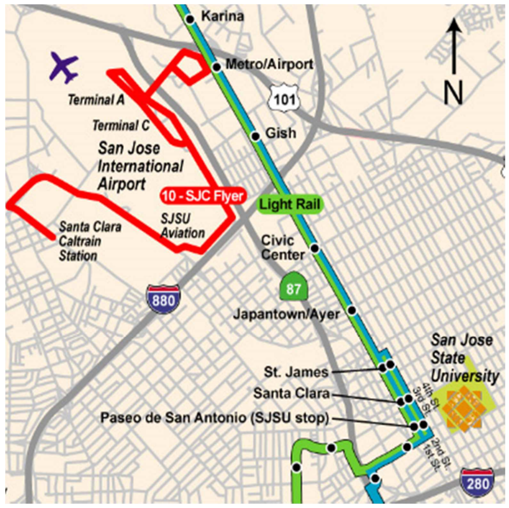


Figure 28: An example of a transportation system. This map describes bus and rail service between SJSU and the airport with indicated stops. (http://as.sjsu.edu/asts/index.jsp?val=sjc)

However, ATNs are neither simple nor monolithic. Proponents of the technology often cite shorter service delays, faster and safer commutes, and energy efficiency as advantages over conventional private and public modes of travel. Yet many such claims remain unsubstantiated and numerous technical issues persist.

If our team wishes to create a PRT system (perhaps worthy of consideration for future implementation by our city), it is necessary to dig deeper to better understand the fundamental principles that make it work. After all, designing a system that meets all our imagined expectations is not without considerable challenges. For example, we might ask ourselves: Where in a given community does one place stations to satisfy demand and provide timely service? How should vehicles be controlled in order to maximize traffic throughput without jeopardizing rider safety? What happens in the event of sudden failure resulting in a stalled podcar on an active guideway? The successful development of a PRT system rests critically on our ability to address these questions by mathematically and scientifically rigorous means.

As such, we foresee that the construction of models will play a central role in our investigations. Not only can models help solve anticipated problems and explore new ideas, the very process of formulating a model from first principles teaches us how the real thing actually works. In essence, models serve as a tool to guide our understanding of the physical world. If we can break the concept of an ATN down to its basic governing rules of operation, we will have begun to lay the groundwork for building our very own system.

The objective of the Networks Group is threefold. First, we wish to learn more about the established theories of ATN design. What are the mechanisms of control underlying these systems of automated vehicles? Second, we will develop a computer simulation of an ATN to give substance to our imagination. We hope that our model will eventually be capable of emulating a real-life system with all its complexities. Finally, we would like the simulation to serve as a kind of virtual laboratory. There clearly are many aspects of ATNs that necessitate further research and exploration. Central to all of our activities will be our aim of advancing our knowledge of transportation systems in a manner that is quantitative and precise.

Background

Understanding Traffic Flow

Why do roads experience traffic jams? This question lies at the very heart of the problem with transport by way of automobiles. However, vehicle congestion is phenomenon that is not unique to cars on highways; it afflicts transportation modes of all kinds (including PRTs). In order to design a system free from such faults and inefficiencies, it is important to understand these problems and their causes in existing systems.

If the motion of vehicles on a pathway were constant and uninterrupted there would be no reason for delays in trips. Cars stop or reduce speed for a variety of reasons, some of which are unavoidable. Red lights, impulsive fellow drivers, and careless jaywalkers are but a few examples. Perhaps these disruptions in the flow of traffic are more consequential than we might think. Exactly what happens when an obstacle appears unexpectedly in the path of a moving car? Let's examine this as we would a simple one-dimensional physics problem.

Suppose that a car traveling at speed v_0 in a single lane encounters an obstacle at time t=0. At time t=τ (after a delay) the driver reacts and begins to decelerate at a constant rate of $-a$. What is the time t_s required to make a full stop? What is the minimum stopping distance d (that is, the position x_0 ahead of the obstacle at which the car must begin deceleration in order to avoid a collision)?

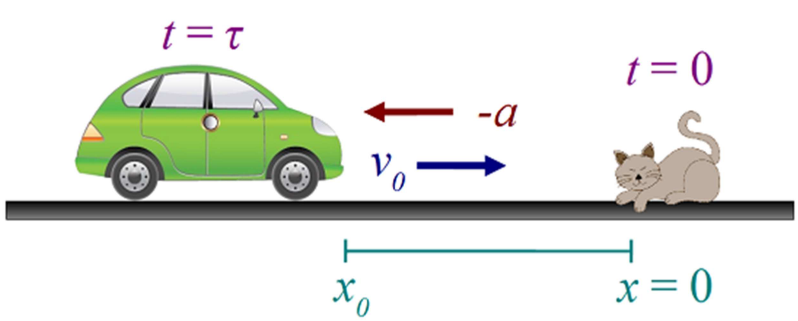


Figure 29: An imaginary scenario involving a driver of a car reacting to an obstacle suddenly appearing in his path.

We can solve for t_s by taking the expression for acceleration as the change in speed divided by time and integrating over time from 0 to t:

$$\frac{dv}{dT} = -a$$

$$\int_0^t dv = -a\int_0^t dT$$

$$t = \frac{v_0}{a} + \tau$$

By integrating the expression for speed over time from 0 to t we can solve for x_0:

$$\frac{dx}{dT} = v$$

$$\int_0^t dx = \int_0^t v\,dT$$

$$x_0 = -\frac{1}{2}a(t-\tau)^2 + v_0 t$$

Substituting stopping time into x_0, we arrive at the following result:

$$d = x_0 = \frac{v_0^2}{2a} + v_0\tau$$

This equation tells us something quite important. Notice that that the minimum separation distance is proportional to the square of the velocity. Therefore, if a car is traveling at twice the original speed, it must begin decelerating at a distance four times as far away from the point of impact than previously.

Now consider a similar but slightly more complicated situation. Suppose the car in the previous example is followed by another car. Let's assume that the driver in the second car (whose ability to react is identical to the driver in the first car) is capable of observing and responding only to the car preceding his own. In other words, the second driver is completely unaware of events that take place ahead of the first car.

Both cars are initially traveling at the same speed. When the first car begins to slow down at a constant rate of $-a_1$, the second driver starts applying the brakes to achieve a constant deceleration of $-a_2$ but only after a time delay of τ. This means that from the time that the obstacle appears at t=0, the response of the driver in the second car occurs at time t=2τ.

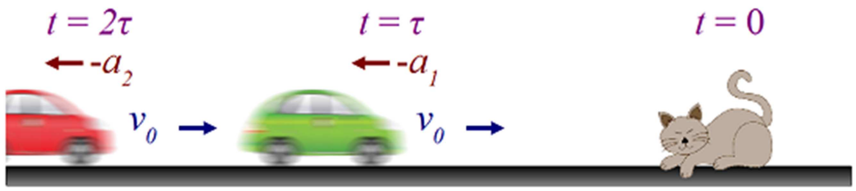


Figure 30: When one car follows another, driver reaction delays are compounded.

With the introduction of another car, two additional parameters must be taken into consideration when determining minimum stopping distance. Given vehicle length L, we will assume that the second driver must stop his car at a distance δ from the rear bumper of the first car.

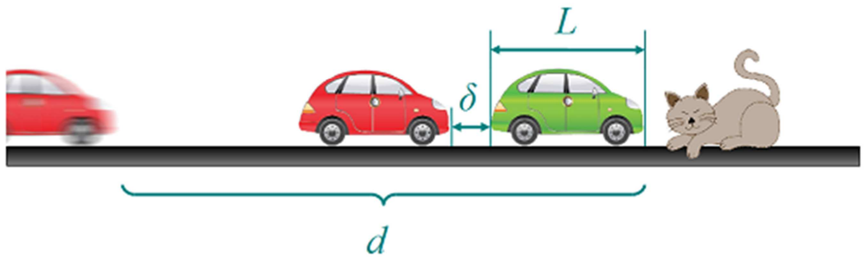


Figure 31: The minimum stopping distance of the second car includes the vehicle length and a gap between it and the preceding car.

If we repeat the calculations performed earlier but with the changes described in the second scenario, we obtain the following equation:

$$d = \frac{v_0^2}{2a_2} + v_0(2\tau) + (L+\delta)$$

The result is identical to that of our single car analysis with two exceptions. First, the driver reaction time (in the middle term) has now increased from τ to 2τ. The second is the appearance of a third term in the equation (accounting for car length and inter-vehicle separation).

What can we understand about the minimum stopping distances of the first and second cars (respectively, d_1 and d_2)? Since both quantities represent the shortest distances required to ensure a full stop without collision, we can interpret the difference $d_2 - d_1$ as the safe driving distance D between two moving cars.

Figure 32: Sufficient spacing must be maintained between cars in motion to prevent collisions when stopping

After subtracting d_1 from d_2 we can group together the acceleration terms and write a simpler form of the equation:

We will analyze further the equation for D in due course. For the moment, it suffices to say that the net separation distance between two vehicles is a combination of three factors, each representative of a particular aspect of driving: non-uniform deceleration, reaction delay, and amount of space that a vehicle occupies.

$$D = d_2 - d_1$$

$$D = \left(\frac{1}{a_2} - \frac{1}{a_1}\right)\frac{v_0^2}{2} + v_0\tau + (L+\delta)$$

$$D = \frac{v_0^2}{2A} + v_0\tau + (L+\delta)$$

We can obtain an alternate interpretation of D by thinking about its inverse quantity. Traffic density ρ is the number of cars within a given segment of pathway:

$$\rho = \frac{1}{D} = \frac{1}{\frac{v_0^2}{2A} + v_0\tau + (L+\delta)}$$

If we plot traffic density as a function of speed based on assumed values of A, L and δ, we obtain the curve shown in Figure 33.

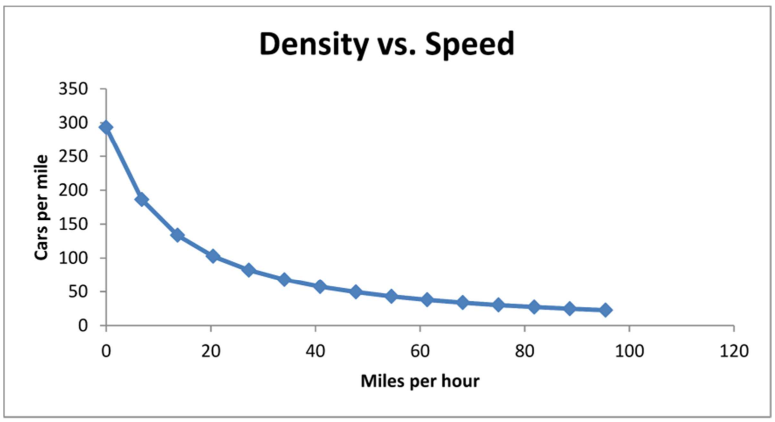


Figure 33: Density decreases as speed increases

Notice that the density decreases as a function of one over speed squared. This relationship probably does not come as much of a surprise. As the road becomes more populated with cars, the movement of traffic slows down dramatically.

Throughput is a concept related to density which describes the number of cars passing through a pathway per time (flow rate). Traffic throughput J can be thought of as the speed at which a given "chunk" of cars moves:

$$J = \rho v_0$$

$$J = \frac{v_0}{\frac{v_0^2}{2A} + v_0\tau + (L+\delta)}$$

Let's plot the equation for traffic throughput:

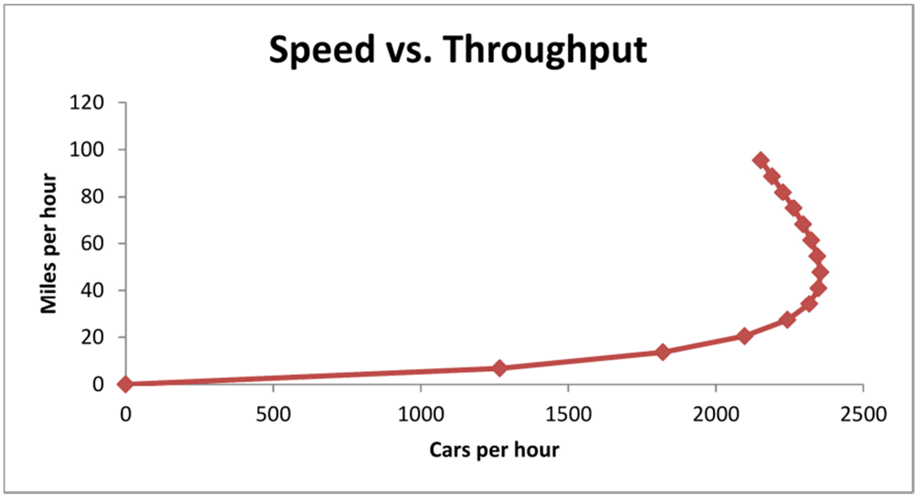


Figure 34: Throughput is optimal at a particular speed

This graph reveals an important characteristic of traffic flow. As expected, throughput is low when vehicles are moving slowly. As vehicles increase their speed, throughput rises—but only up to a point. There is clearly a speed at which throughput reaches a maximum before steadily declining despite vehicles moving ever faster.

Our findings appear to corroborate the results of two prior studies: a quarterly report released by the Department of Transportation in the state of Washington and a paper authored by Kwon (California State University) and Varaiya (University of California). In both cases, actual data was collected from highways/freeways known to carry large volumes of vehicular traffic.

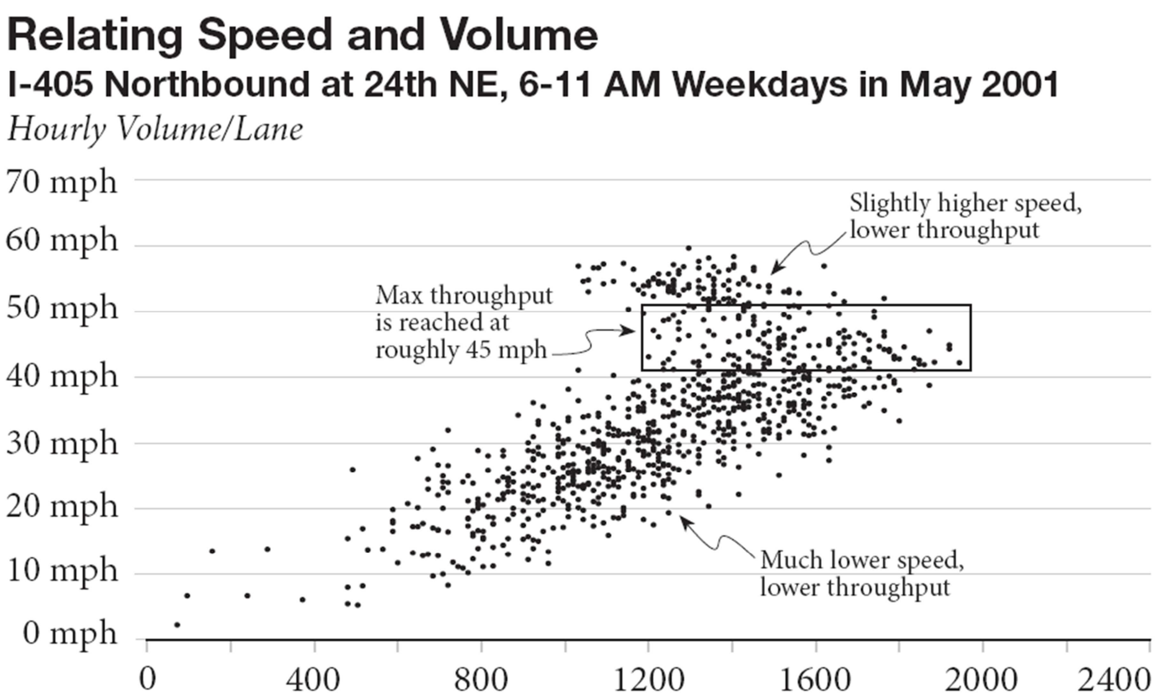


Figure 35: Maximum throughput occurs at speeds between 40 and 50 miles per hour according to a report released by Washington State (MacDonald, 2006)

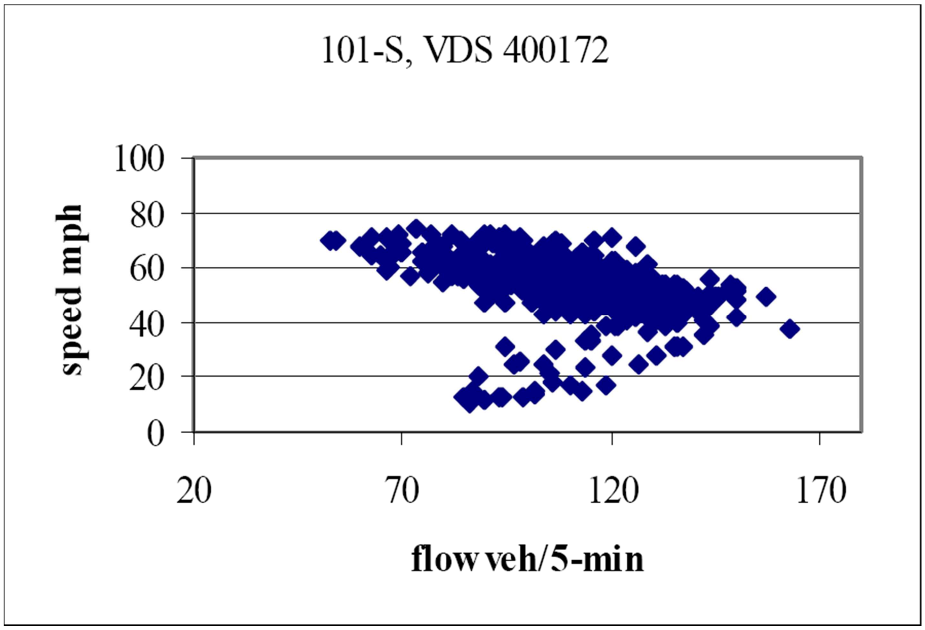


Figure 36: A graph indicating peak throughput at approximately 50 miles per hour in a study of HOV lanes in the San Francisco Bay Area (Kwon & Varaiya, n.d.)

When generating our own graphs, we intentionally selected values of A, L and δ to match the figures presented in the aforementioned publications. While applying different values to those parameters will affect specific points on the plot, the curve retains its general shape.

$$D = \boxed{\frac{v_0^2}{2A}} + \boxed{v_0 \tau} + \boxed{(L+\delta)}$$

Let's now return to our discussion concerning safe driving distance. Recall that:

A great deal about the nature of traffic flow can be deduced here. The three terms in the equation each represents a factor in explaining the how cars are spaced along a road:

1. As noted earlier, separation distance is proportional to the velocity squared. Vehicles traveling at even moderately higher speeds require much greater spacing. This factor will remain dominant so long as the rate of deceleration is not uniform among cars (variations in driver braking behavior).
2. No driver behind the wheel of a car can react instantaneously to events on the road. Moreover, it is not unreasonable to assume that drivers generally do not focus their attention much further beyond the vehicle immediately before them. Reaction delays and limits to knowledge are likely to have a significantly impact.
3. Drivers are incapable of precisely judging distances and applying brakes in such a way to keep gaps between vehicles necessarily small. And of course, cars are finite in size. Larger (and heavier) vehicles require especially greater distances. Thus, the contribution of this factor can be quite substantial.

At the heart of this discussion is a dimension that, though routinely taken for granted, is the single most important determinant in establishing safe driving distance: the human being. Though humans excel in a great many mental and physical activities, driving is apparently not one of them. The human being is in fact the principal cause of roadway inefficiencies.

Well, what happens if we take ourselves out of the equation? Suppose that cars are driven not by people freely on roads but by computer on fixed paths. Because computers operate according to predetermined rules under specific conditions, every vehicle in the same situation behaves in the same way. The computer has the ability to rapidly process knowledge about its surroundings, enabling the car to respond immediately to events on its path. Additionally, communication between computers can be nearly instantaneous and are not restricted by physical barriers. Each car is therefore capable of knowing what other cars in the vicinity know. Finally, suppose that all computers are linked to a mainframe that functions as the central decision making authority.

The outcome of substituting man with machine in cars is a system that exemplifies an ATN in the broadest sense. Let's consider the implications of these changes with regard to safe driving distance.

1. Computer control will guarantee consistent braking behavior in all vehicles. Once the capability for uniform deceleration is realized, the $1/A$ term becomes zero and velocity squared term in the equation vanishes.
2. With the human extricated from the driver's seat, delays in reaction time and handicaps in sensory perception are no longer a problem. There may still be very small delays associated with detection and response depending upon implementation but these intervals will certainly be vastly smaller than those caused by humans.
3. Any physical vehicle no matter the driver will occupy a fixed amount of space so this last term will still persist. The gap between cars may be shortened, however, by bringing cars closer together when slowing down or stopped.

In all practicality, the third term in the equation for D is the only component contributing to safe driving distance that remains significant.

Through our derivations and calculations, we have identified the very human problem with cars on roads, our predominant method of travel at the moment. We clearly are in desperate need of an upgrade. So what makes a better system? There are three features that would make a transportation system more efficient:

- Automation
- Coordination
- Centralization

As we have demonstrated, automation brings consistency and predictability to a system. Coordination improves the integration of individual units so that they behave in a concerted fashion. A certain degree of centralization enables better system-wide planning and more effective resource management. Together, these three elements form the foundation for the design of an automated transit network.

Insights From Aerospace Corporation Report

Under the direction of the City of San Jose Department of Transportation, an ATN feasibility study was performed by the Aerospace Corporation, the results of which were released to the public in October 2012. Though the report contains quite a detailed examination of an array of topics, the discussions pertaining to networks are of principal interest to our group.

Perhaps one of the greatest obstacles to the realization of the ATN as a truly viable mode of transit is the lack of an accurate and comprehensive understanding of the system in a real-world environment. As the Aerospace report explains, numerous attempts have been made to characterize ATNs using mathematical equations and computer models. Yet many of these representations are flawed due to gross oversimplifications and superficial treatment of non-trivial matters. The systems that do provide more realistic portrayals of ATNs are usually kept under the purview of those holding intellectual property rights. In any case, no system, open-source or otherwise, has been subjected to thorough and rigorous testing in the field.

A final point: theories and models of generic ATN designs, however exact and exhaustive they may seem, have inherent limitations. The performance and reliability of a system depends heavily upon its specific implementation (corresponding to factors such as urbanization, geography, climate, etc.). Thus, studies of ATNs must be conducted on a case-by-case basis if predictions are expected to be accurate.

The functional capabilities of an ATN may be described in terms of time, distance, and speed. Headway, capacity, and throughput are concepts particularly useful in evaluating the performance of transportation systems.

Headway is a measure of the spacing between vehicles. It is the frequency of arrivals at a fixed reference point along a guideway:

$$headway = \left[\frac{time}{vehicle}\right] \text{ or } \left[\frac{vehicle}{time}\right]$$

Both speed and the spacing between vehicles are related to headway. In fact, headway can be expressed as a function of those two terms:

$$headway = \frac{spacing}{speed} = [distance] \times \left[\frac{time}{distance}\right]$$

By specifying one quantity in the relationship, the other two can be adjusted with respect to each other. For instance, a headway of 6 seconds can be achieved either by a speed of 20 miles per hour with a spacing of 176 feet or by a speed of 40 miles per hour with a spacing of 352 feet.

Line capacity describes the maximum rate of people that a stream of vehicles can carry. It is expressed as the number of seats per hour:

$$line\ capacity = \left[\frac{seats}{time}\right]$$

Line capacity is actually a product of three factors: headway, vehicle capacity (passenger-carrying capacity of each vehicle) and percentage of vehicles occupied:

Based on published estimates, vehicle capacity is generally assumed to be about 30% (based on comparisons to conventional automobiles). Although the proportion of occupied vehicles varies,

$$line\ capacity\ =\ headway\ \times\ vehicle\,capacity\ \times\ \%\ of\ vehicles\,occupied$$

$$line\ capacity\ =\ \left[\frac{vehicle}{time}\right] \times \left[\frac{seats}{vehicle}\right] \times \left[\frac{occupied\ vehicles}{all\ vehicles}\right]$$

studies suggest that a figure of 80% may be a reasonable benchmark.

For these last two parameters, it is worthwhile to point out that ideal values in a PRT system are somewhat contrary to those one might expect for traditional public transit. Because of the inherently “personal” nature of the PRT, each vehicle is specifically designed for low occupancy. By the same token, empty vehicles are a desired feature in such a system. If shorter station wait times are to be achieved, unoccupied vehicles must circulate continually inside the network so that they may be called upon at any moment.

Safe headway refers to the separation distance that must be maintained between two vehicles so that both are able to stop for any reason without colliding. The discussion of safe headway is a rather lengthy one; we will introduce only the the brick wall stop criterion for the sake of brevity.

Brick wall stop (BWS) is an imagined “worst-case scenario” in which a large immovable brick wall magically appears in front of a vehicle forcing its driver to decelerate in such a way so that impact is avoided by just a hair. In essence, this scenario is equivalent to the one presented in our study of the reasons behind aggravated traffic congestion.

At present, ATN systems in review all operate at safe standards well beyond the BWS criterion. At a headway of 6 seconds, line capacity is held at around 1,920 seats per hour. With the implementation of BWS, it is estimated that a headway of 1.8 seconds is ideally achievable, bringing the line capacity to 6,400 seats per hour. This would result in a three-fold improvement in capacity over current designs.

The authors of the Aerospace report make a bold proposition: discard the BWS criterion entirely. Since every moving object has mass, BWS scenarios are in fact not at all realistic and lead to unnecessarily strict regulations. In the absence of BWS, line capacities of more than 10,000 are possible if a headway of 1.1 seconds can be attained.

One important consideration relevant to this discussion is the limits of human endurance. While technically feasible, powerful decelerations pose a serious threat to the comfort and safety of passengers. Jerk is a term used to describe the rapidity of deceleration (expressed in [distance / $time^3$]). The appropriate amount of jerk for an emergency stop is ultimately determined by the ability of passengers to physically withstand such a shock. A deceleration of 0.6g corresponding to a jerk of 2g per second is considered too aggressive (riders are unable to adequately brace themselves). Nominal estimated deceleration is reported to be 0.1g. Current ATN designs feature values ranging between 0.25g and 0.5g.

Simulation

Once we determined that the solution to human-driven cars on roads was autonomous vehicles on guideways, we moved ahead to build such a system on computer. We began development using Python language in conjunction with the Pygame engine (for graphics). Presently, our program is capable of demonstrating the movement of an object along linear paths within a simple network:

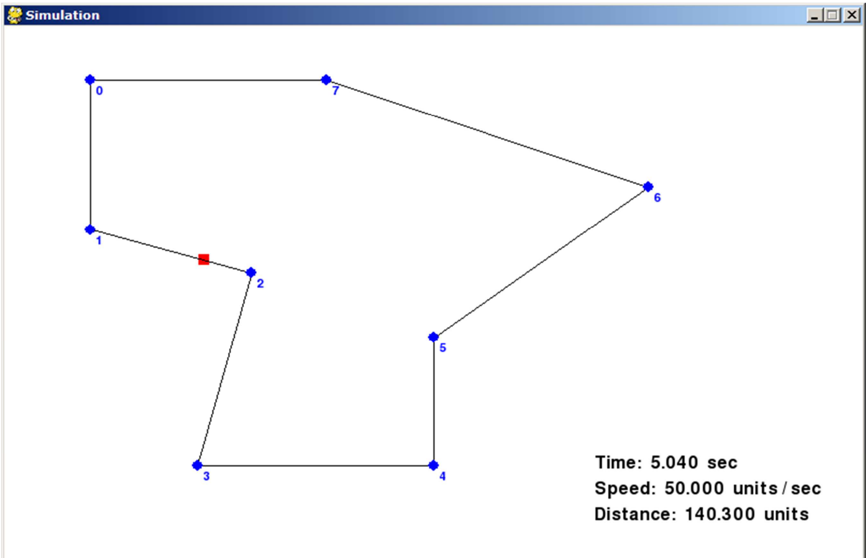


Figure 37: A screen-shot of the computer simulation in progress

At execution, the program moves a vehicle (red square) at constant speed among a group of nodes (blue circles) joined by straight pathways (black lines) in a prescribed pattern. The user can click and drag any node on the screen with a mouse to change it's coordinates while the simulation is running. The nodes are dynamically linked such that when one is repositioned, the affected pathways immediately adjust their length and orientation in response. As the vehicle traverses a pathway, it too adapts to structural modifications in the network by changing its direction of motion in real-time.

Conclusion

The idea of the ATN/PRT is not a novel one (with the passage of more than fifty years since its conception). Yet public awareness and interest has lagged. Even among circles of experts and professionals in the transportation field, advocacy for the ATN has been sorely lacking. Meanwhile, the body of evidence pointing to the urgent need for such a system only continues to mount. As our towns and cities continue to expand, traveling from one place to another becomes an increasingly tiresome daily struggle.

In the face of extraordinary technological advances in recent decades (especially given the power and ubiquity of modern computing), one wonders why automated transportation systems are almost nowhere to be found. There are surely many reasons for this, but a fundamental one that the technical community recognizes is the lack of knowledge. The ATN may hold many promises but it also brings considerable uncertainty.

Transit networks are incredibly complex systems. Despite extensive study and research, people are really just beginning to understand how they work. Our own group's explorations over the past several months have certainly been enlightening and rewarding. But given the depth and expanse of the subject, we have only barely scratched the surface.

As newcomers to the field, we began by first trying to understand traffic congestion (a phenomenon with which we are all too familiar, unfortunately) by means of an elementary physics analysis. We discovered, perhaps not too surprisingly, that the culprit behind the sluggish automobile roads was ourselves—the human being. By automating, coordinating, and centralizing the control of vehicles, we can drastically improve the way we transport people.

We then set out to tackle the automated transit network by creating computer models to represent their structure and behavior. By marrying together our knowledge of mathematics and computer coding, we were able to begin constructing a simulation program. We hope that once minimal functionality is established, this program can serve as a framework and testing platform for many future activities. Ultimately, we envision a program that will be capable of executing a variety of tasks: performing traffic merges, identifying inefficiencies in the network, predicting responses to failures, and more. Though still in its infancy, we hope that our virtual ATN will grow into a useful tool for helping us better understand transportation systems

We look forward to continuing our investigations with great enthusiasm and aspiration.

Chapter 10: Final Design

Cabin

This section will describe the various preliminary design concepts that are included both in the interior and exterior of the cabin.

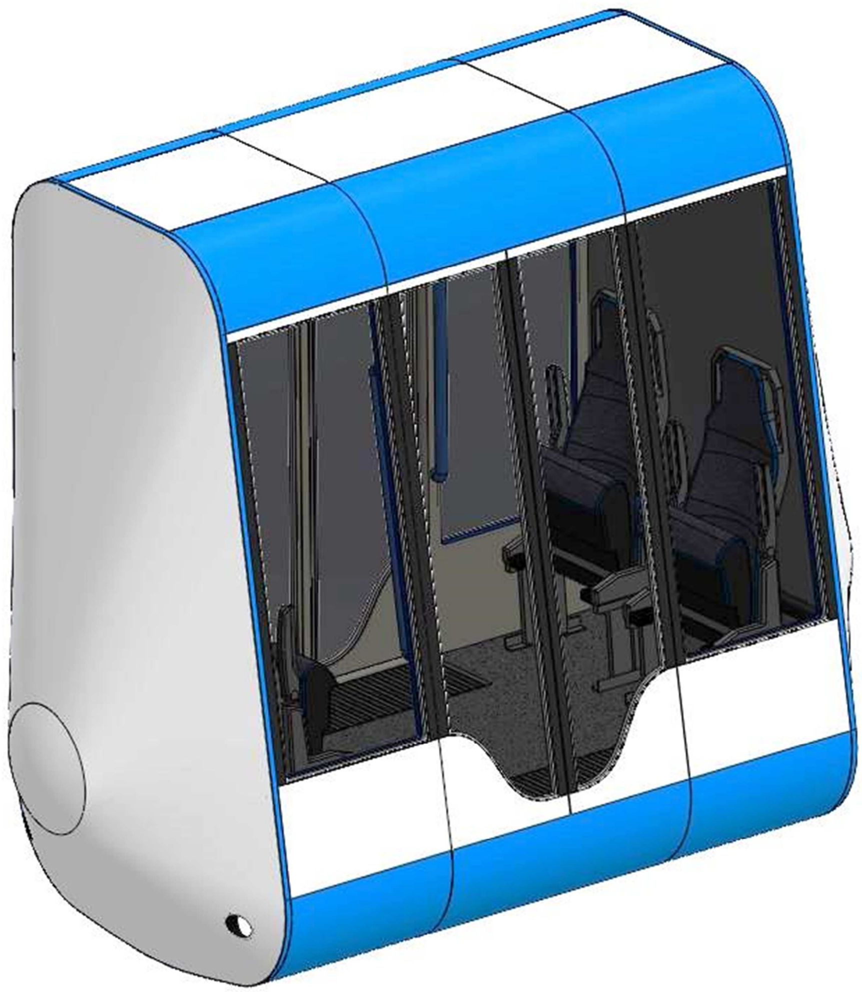


Figure 38. Final design of the cabin

Human Factors

Before any design and revisions were made, human factors were considered since they play a big role in cabin design and sizing. The human factors that were taken into account for this design of the cabin resented in the paper are the seat distance and the height of the cabin. According to the

Center of Disease Control and Prevention, the average American male height is 5.9 feet. The average female height was not considered into the design because it was much shorter than the average male height. The height of the doorway, which was originally 5 feet, was raised to 5.9 feet to accommodate a larger range of people. The overall floor to ceiling height in the original cabin design was 5 feet. This presented a problem with getting in and out of the cabin without injury, removing strollers and other luggage. The height has been raised to 7.8 feet to accommodate these needs along with being more aerodynamic.
To determine a comfortable distance between seats, a mockup of the seat arrangement of the cabin was made and tested by five people varying from 5ft. 6in. to 6ft. 2in. tall. From this mock up, it was determined that the distance from the front edge of one seat to the front edge of the seat directly across is 41 inches. The distance between two seats next to each other is 5.5 inches.

Seating Configurations

Original Six Seat Configuration

The original intent for the cabin design was to have three seats on the front and rear of the cabin. Each of these rows of seats was to be individual bucket seats. Figure 39 shown below is the original six seat configuration.

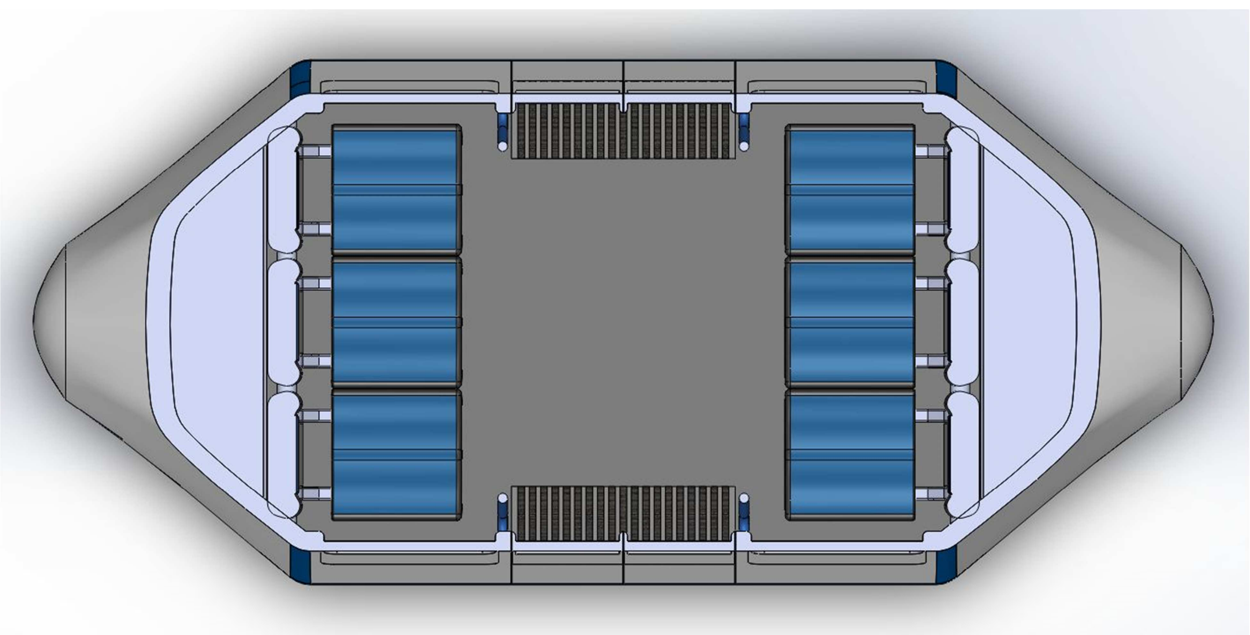


Figure 39. Top View of 6 person configuration

Bucket seats allow each of the passengers to have personal space. In addition, bucket seats are more comfortable than bench seats because of how the bucket seats “hug” your body. Bucket seats are especially helpful in holding the passengers in their seats during turns and banks at high speeds, while bench seats would cause the passenger to slide. Although there will be a weight sensor on board (cabin does not move if it is too heavy), rows of bench seats would invite too many people to go on board. This will cause more incidents of passengers who will have to get off and wait for the next cabin.

The original design called for two rows of custom bucket seats. This would obviously be too expensive because a company would have to manufacture each of these seats from scratch, so the team searched for existing solutions. The team found a reputable company, Freedman Seating, who designs and builds many types of transit seats (Freedman CitiSeat, 2009). These seats are great because they fold to create more space, as well as a flat surface for ADA compliance. The CitiSeat Flip model comes in one, two, or three person rows of seats, which perfectly matches our needs.

The original seating arrangement of rows of seats at each end of the cabin allows for the maximum utilization of the space in between the seats, especially when the seats are folded in the upright position.

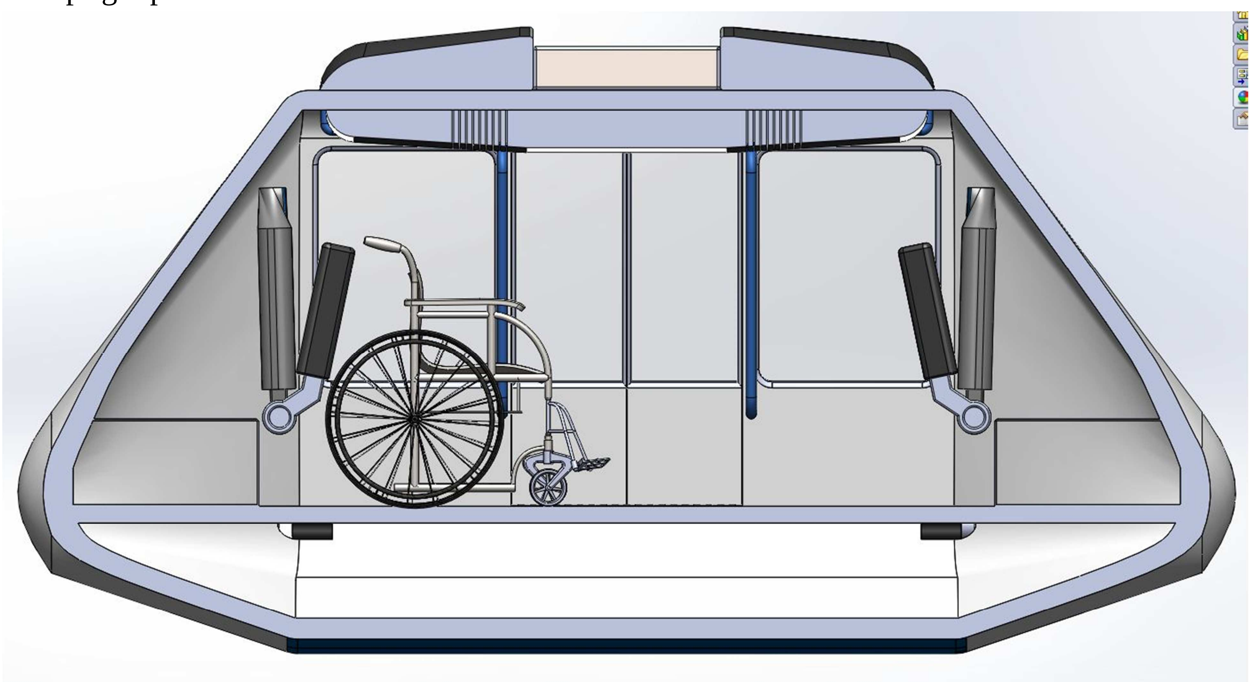


Figure 40. Wheelchairs have more than enough room to fit and maneuver

In addition, it easily meets ADA compliance and regulations (in regards to wheelchair space) since the length and width of the cabin already exceeds the minimum space needed, which is 30 inches by 48 inches.

As one can see, the “face to face” seating configuration is the most preferable since it allows for the maximum amount of space and easily exceeds ADA compliance. The main issue at hand, then, is whether to have the capacity for 4 or 6 passengers.

One argument for 6 passengers relates to the width of the cabin. With 6 passengers, the width of the cabin will be wider, which increases aerodynamic drag (larger cross section) as well as increasing the amount of material needed to build each cabin. With 4 passengers, the cabin can be narrower, which decreases the aerodynamic drag and the material needed. Furthermore, the total weight of the cabin would be less, which decreases energy consumption throughout the system. However, if the system is to be implemented in Santa Cruz, a 6 passenger capacity would make more sense. For instance, the Morgantown PRT system serves students, faculty, and anyone who would like to ride it. The maximum capacity is about 20 passengers. Students and faculty generally do not care about having their own cabin, but instead, getting to/from school as quick as possible. The only way this can be done is to have a larger capacity. If UC Santa Cruz is part of the corridor, then more passengers would be more beneficial. If a cabin comes every two minutes, and there is only a four person capacity, that would be 120 passengers per hour. If there is a 6 person capacity, that number would be increased to 180 (60 more passengers per hour). Students and faculty would rather arrive at their destination quicker.

Another issue is that with the current design of six people, the height from floor to ceiling is only 5 feet, making it difficult for many people to move about the cabin(especially when trying to turn around and sit down). Increasing the height is a simple solution, but also comes with many drawbacks as well. If the overall height of the cabin is increased, then it would cost more money per cabin due to the added material and increase aerodynamic drag which also increases energy consumption.

Another Six Seat Configuration

If the cabin height is to be kept at a current 5ft from the bottom to the top of the cabin, different seating configuration need to be looked into besides the one for the current design. The problem with the current seating configuration is discussed in a different section. The seating configuration presented in this section keeps the 5ft height and solves the issue of someone's bottom being in another passengers face when entering and exiting the cabin.

The seat configuration shown in Error! Reference source not found. is not feasible for this system. In order to meet Federal and State law for wheelchair accessibility, the width of the cabin for this seating configuration would need to be at minimum 117.5in. The foldable seats that were used to obtain the dimensions need to calculate the minimum width of the cabin were CitiSeat by Freeman. When folded, these seats are 10.75in thick, as shown in Figure 41**.** According to Federal and State laws, wheelchairs need a 32X48in turning space width the cabin. Since the cabin's design must satisfy this law, the distance from the door a folded seat directly opposite of the door would need to be at least 48in. Since both sides must be the distance from the folded seat to the door, this distance alone means the cabin must by at least 96in long.

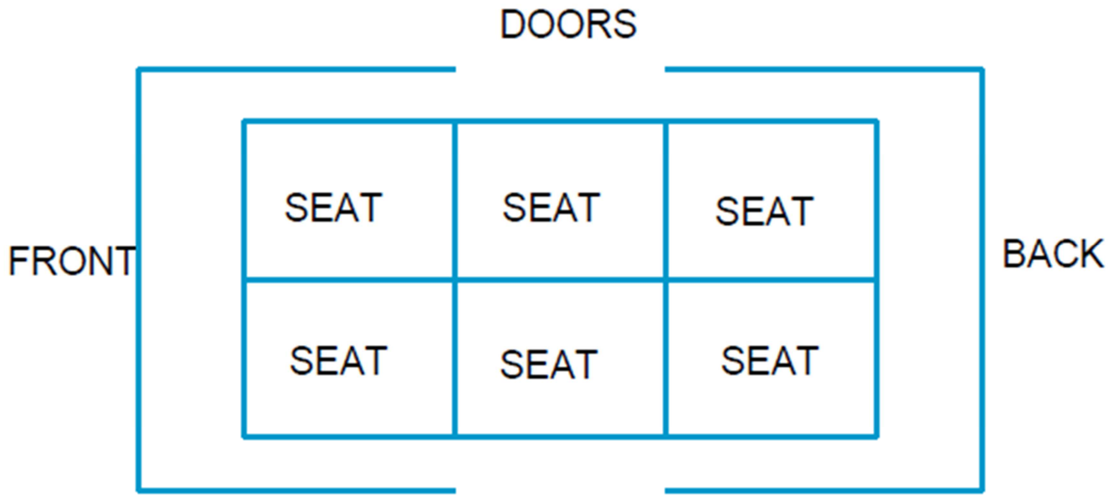


Figure 41: Six Seat Configuration

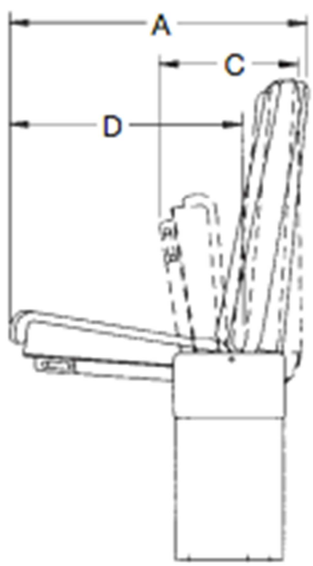


Figure 42: CitiSeat by Freeman. Retrieved from http://www.freedmanseating.com/images/uploads/files/CitiSeat.pdf

This 117.5in adds to the material cost, drives up the weight of the cabin resulting in the need of a stronger structure, and bogie attachment, and more energy required to move the cabin. A larger station will also be needed because of this dimension.

Four Seat Configuration

A four-seat configuration will eliminate some of the obstacles associated with six-seat options. By orienting the seats as shown in **Error! Reference source not found.**, space issues that are present in the six-seat configurations are eliminated. In addition, the possibility of discomfort experienced from having another rider's bottom in another's face because passengers can board the cabin in a manner more similar to climbing into an automobile is also reduced. By having just four seats the experience would be closer to riding in a car, in this manner this might encourage possible passengers to use the system. A four seat option still allows for wheelchair accommodation and is thus ADA-compliant while allowing for a reduction in the length of the cabin. This translates into a reduction in materials, stooping to enter the cabin will also not be as much of an issue when boarding the cabin. A reduction in materials also means less drag force which plays a significant factor in a suspended system like the one that has been propose because the cross-sectional area of the front and back will be smaller.

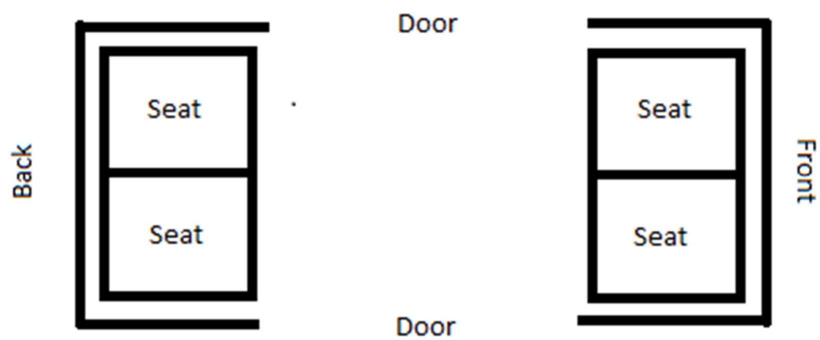


Figure 43: Layout of four seat configuration for cabin

However, by eliminating two seats, the possibility of carpooling might be significantly reduced as compared to a six-seat option. The four-seat option does allow for a more intimate experience when using the system—with the six-seat option, it is assumed that some riders will be comfortable with sharing a cabin with strangers to reduce ride cost. With the four-seat option, the discussion of bench versus bucket seats is virtually irrelevant.

Simplified Drag Force Calculation

For simple analyses purposes, the six-seat and four-seat cabins were compared to show that the final design of four seats saves energy by decreasing the amount of drag.

The primary reason that the preliminary design was revised is due to aerodynamic drag and drag force. The six-seat design had a wider body due to a row of three seats on each side, which means a larger cross section. The final design of four seats has a narrower body due to only two seats per side. The narrower body reduces the cross section.

The cabin can basically be modeled as a cube (3D) since the side-profile is similar to that of a box.

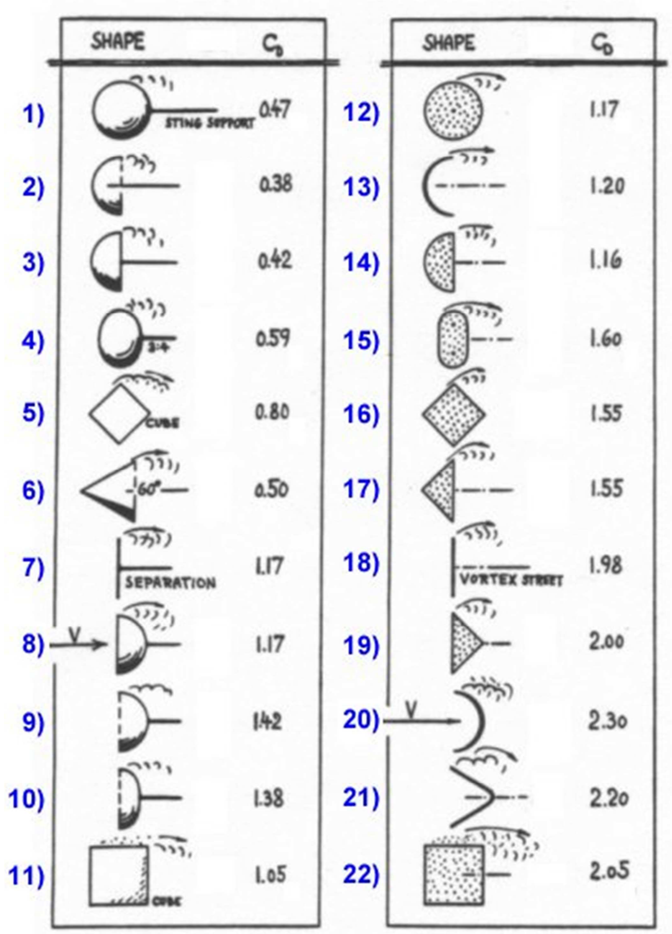


Figure 44. Table of Drag Coefficients

As seen in **Error! Reference source not found.**, the coefficient of drag for a cube is 1.05. Using the coefficient of drag (C_d) with the formula for drag force (shown below), the drag force for both the preliminary and the final/revised design can be found.

$$F_d = \frac{1}{2}\rho v^2 C_d A$$

For this formula to be used correctly, SI units must be used. The following values are inputted for each of the respective designs, and the drag force is calculated:

Table 4. Drag Force Calculations

	Six-Seat Design	**Four-Seat Design**
Density (ρ)	1.27 kg/m^3	1.27 kg/m^3
Velocity (v)	15.65 m/s (35 mph)	15.65 m/s (35 mph)
Width	80.7 in	55.5 in
Height	72 in	95 in
Area (A)	3.75 m^2	3.40 m^2
Coefficient of Drag ($C_{d)}$	0.80	0.80
Drag Force (F_d)	**466.6 N**	**423.0 N**

As seen in Table 4. Drag Force Calculationsabove, the four -eat design has almost 44 N less drag force compared to the six seat design.

Pugh's Method

To further justify a four-seat cabin configuration verse the two six seat configurations, the Pugh's Method was applied to all three choices and show in Table 5: Pugh's Method applied to 3 different seating configurations below. Pugh's Method is a visual representation of prioritizing the customer's wants and need so the designer has an idea of which key features to focus when designing. The weight of importance is based off a 1 to 10 scale with 1 being the lowest and 10 being the highest. If the alternative meets a feature that the customer wants or needs, a '+' is given. If the alternative does not meet a given feature, a '-' is given. The numbers are then added or subtracted based off of the '+' or '-' given under that alternative. The 'S' means datum. This is a required feature that must be included into the design. All of the seating configurations presented in Table 5: Pugh's Method applied to 3 different seating configurationsTable 5 below meet the requirements.

Table 5: Pugh's Method applied to 3 different seating configurations

	Weight	Original 6 Seat	Alternative 6 seat	4 seat
Comfortable	9	+	+	-
Light Weight	8	-	-	+
Safety	S	S	S	S
Aerodynamics	10	-	-	+
ADA complaint	S	S	S	S
Storage	7	+	+	-
HVAC	S	S	S	S
Total	34	16	16	18

By Pugh's Method, it is clear that the 4 seat configuration is the winning design. After determining the seating capacity and configuration, the exterior, interior, and each of the components can be designed.

Exterior

The general exterior shape of the cabin has been influenced by both past and present shapes and designs. Starting with the nose(s) of the cabin, aerodynamics was kept in mind. An aerodynamic nose minimizes drag and friction, allowing the cabin to consume less energy. The system would consume less energy due to the fact that there would not be as much power needed for the cabin to cut through the moving air.

Instead of one pointed nose at one end, the cabin has two pointed noses at each end allowing for bi-directional travel. This is seen in both present and previous systems including ULTra, Vectus (both mentioned in the State-of-the-Art section), and the Masdar PRT (PRT Application Characteristics, 2013). One of the advantages that this cabin design has above the ones listed is the fact that it has space in the cabin to fit a full-sized bicycle. The Beamways design allows for a bicycle to fit, but is not shaped to be bi-directional.

Therefore, the design shown below takes the bi-directional shape of ULTra, Vectus, and Masdar, but retains the versatility and space of the Beamways design.

The noses, 14 inches in length each, blend smoothly into the main cabin section, which is 80 inches long (both interior and exterior). The total length is 108 inches as shown in **Error! Reference source not found.**.

Interior

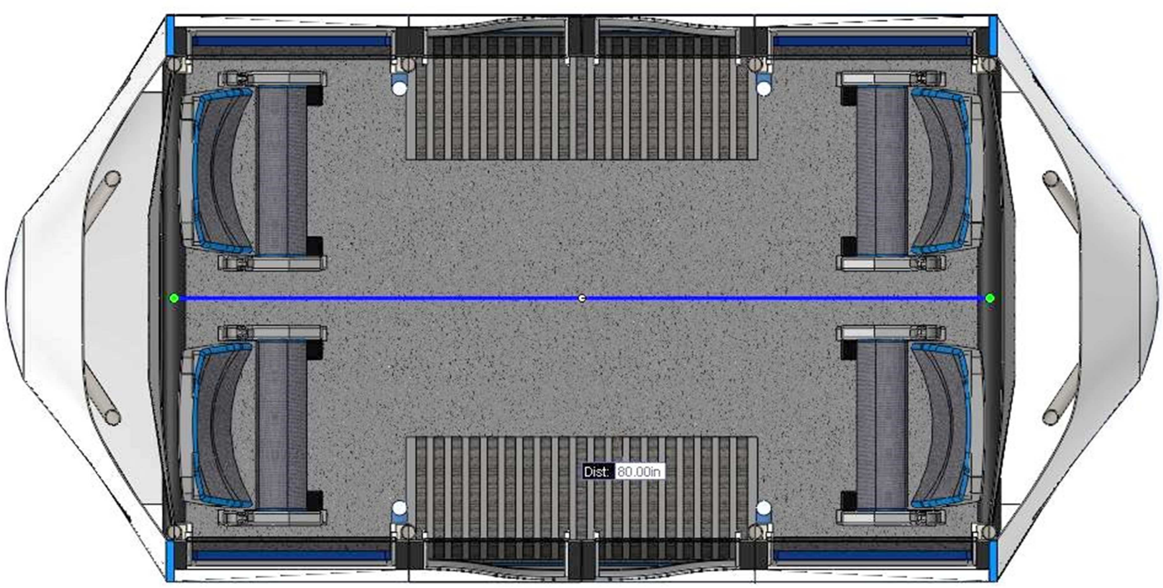


Figure 45. Cabinfloor length is 80 inches

The floor length needs to be long enough in order to incorporate a sufficient length for bicycles. The average length of a bicycle from the front edge of the front tire to the rear edge of the rear tire is about 5 to 6 feet, or 60 to 72 inches (General Design Factors MN/DOT Bikeway Facility Design Manual, 2007). The length is of the floor on our design, which is 80 inches is greater than the average length of 72 inches; therefore, a bicycle can fit in between the seats with no problems.

Although the width of the exterior of the cabin is 56 inches, the width of the interior cabin floor space is about 52 inches (Figure 46) due to the panel thicknesses and frame. The floor width of the cabin was designed after sizing the seats through human factors testing.

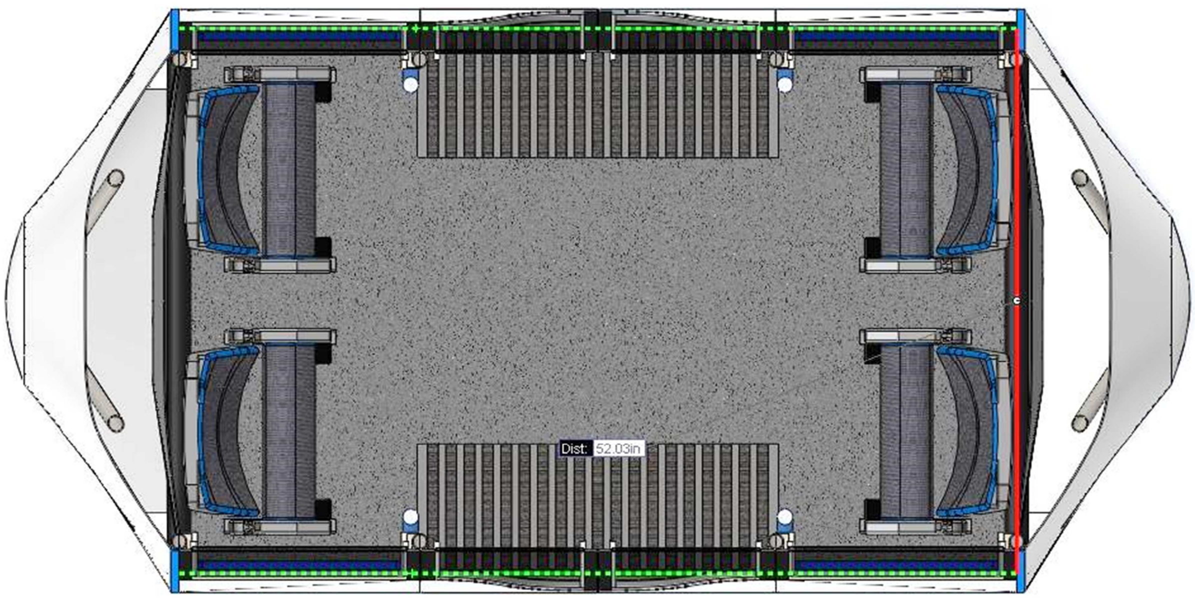


Figure 46. Floor width is approximately 52 inches

As mentioned in the Seating Configuration section, each end of the cabin has a row of two seats. The seats are individual bucket seats which allows for more personal space in a smaller and more intimate seating configuration.

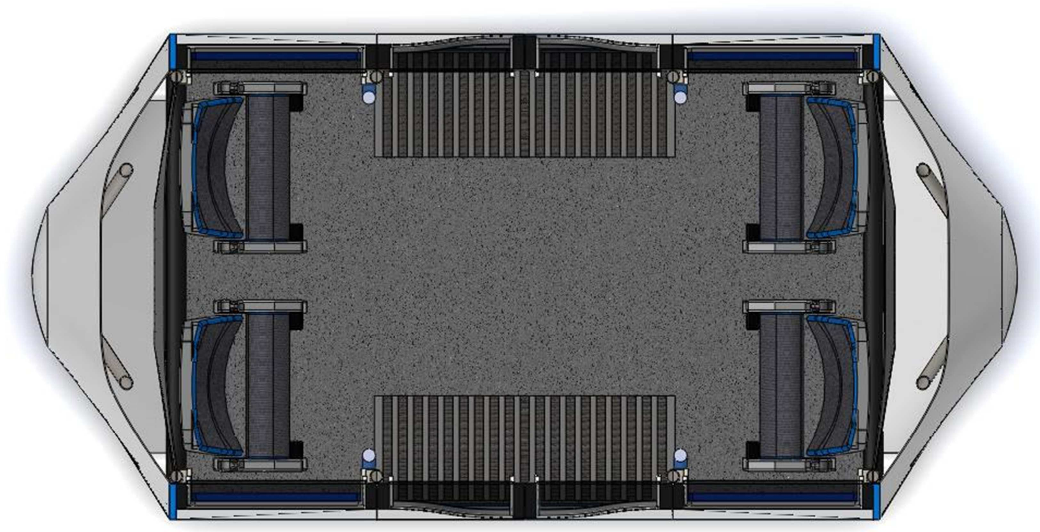


Figure 47. Top view shows two seats at each end of the cabin

Each of the rows of seats has 5.32 inches in between to allow the wheels of a bicycle to fit and be secured**Error! Reference source not found.**).

Figure 48. Space between seats allow for bicycle wheels to fit

Seat Design

The seat utilizes a movie theater style seat, in which the normal position of the seat bottom is folded up (**Error! Reference source not found.**). When a passenger is ready to be seated, they will fold down the seat bottom and sit down as shown in Figure 50. Seats in folded and neutral position.. Note that the armrests can be folded as well to increase the amount of space needed.

Figure 49. Neutral position of seat. Passengers will fold down the seat bottom to be seated.

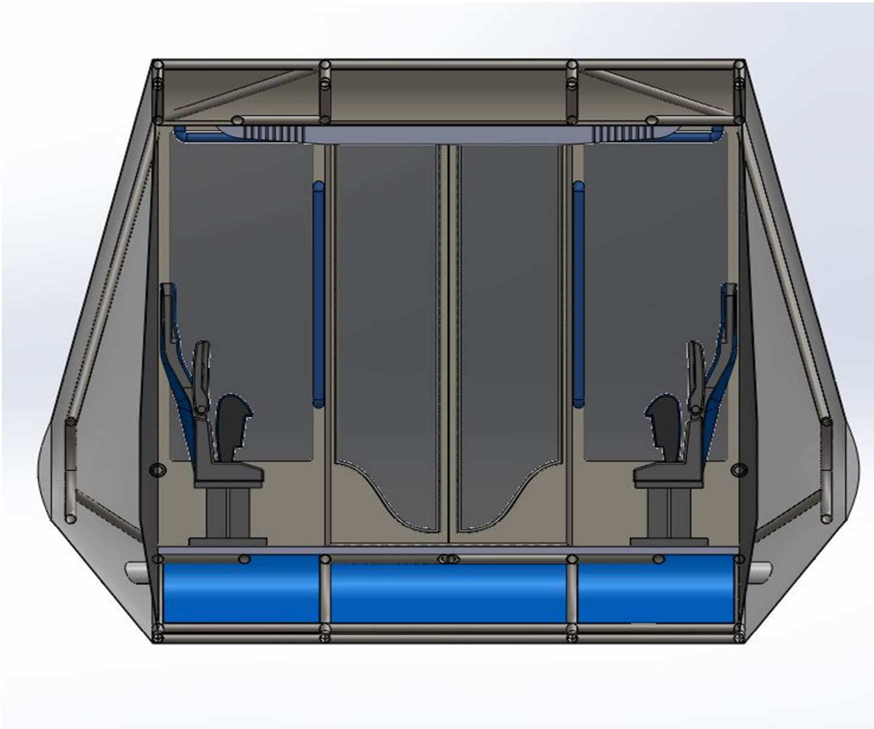


Figure 50. Seats in folded and neutral position.

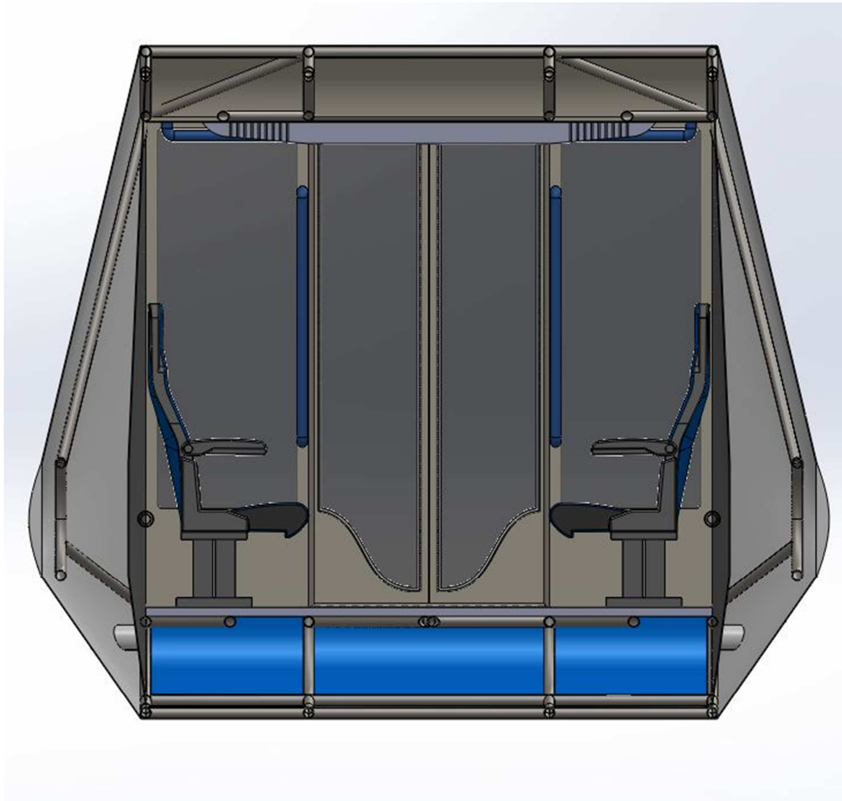


Figure 51. Side view of seat bottoms folded down to simulate passengers being seated

Figure 52. Seat bottom in "engaged" position.

When the seat bottoms are folded down, they are supported by blocks on both sides. The blocks are attached to the main seat bracket to ensure rigidity.

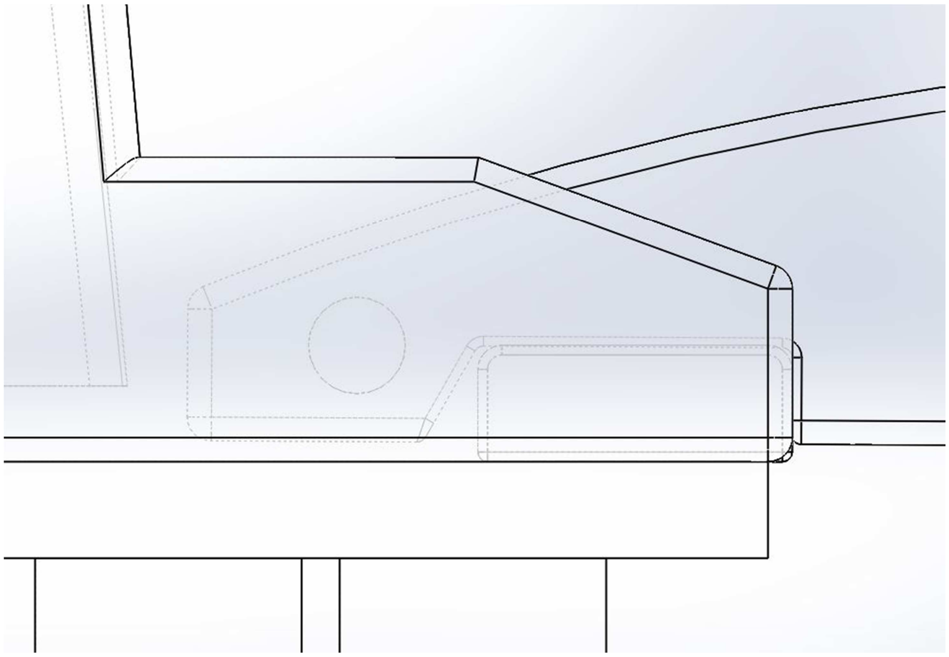


Figure 53. Blocks attached to the seat bracket support the seat bottom in the folded position

The seats will be upholstered with vinyl. Vinyl is inexpensive, but provides comfort that more rigid plastic seats cannot. In addition, vinyl fabrics can provide the same aesthetics of a more luxurious fabric, such as leather, while allowing for the easy maintenance. It can be wiped down easily and is not entirely porous, so it does not trap odors.

Other considerations for folding seat mechanisms were made by the team, which include seat bottoms supported by a folding column or a support that moves along a hinge.

Spring Design for Seat

As mentioned previously, the seat utilizes a movie theater seat like design and features two helical torsion springs to facilitate this motion. It was estimated that approximately 10-15 lb force would be a reasonable requirement for an able-bodied person to push the seat down in order to sit in it. Using two springs, each spring is subject to a 5-7.5 lb force to move through the 90 degree (0.25 revolutions) deflection to bring the bottom of the seat from an upright to downward position. An Excel spreadsheet was used to go through the iterative process required to size the springs. For the purposes of calculations, the spring was designed using unpeened music wire (ASTM A228) having a wire diameter of 0.192 in. and the resulting requirements are outlined in **Error! Reference source not found.**. The detailed calculations can be found in Appendix D. The rod that acts as a pivot point has a 1 in. diameter and the maximum allowable pin diameter is 1.37 in. there is plenty of clearance between it and the spring in the downright position.

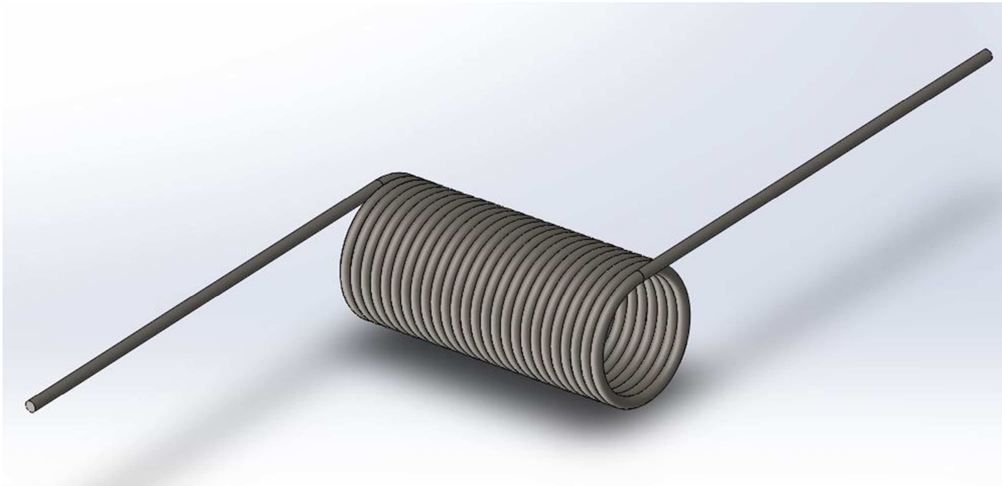


Figure 54. Torsion spring model after sizing

Table 6. Dimensions for Seat Springs. The requirements for the seat springs to be manufactured to rotate the seat from the upright to down position are outlined below.

Coil Diameter	1.73 in
Number of Body Coils	26
Spring Rate	80 lb-in/rev
Outside Diameter	1.92 in.
Inside Diameter	1.536 in.

ADA Compliance

Having the ability to fold rows of seats is important, especially for those with wheelchairs. ADA regulations state that a space of 32” x 54” is required for wheelchairs, in which this design satisfies.

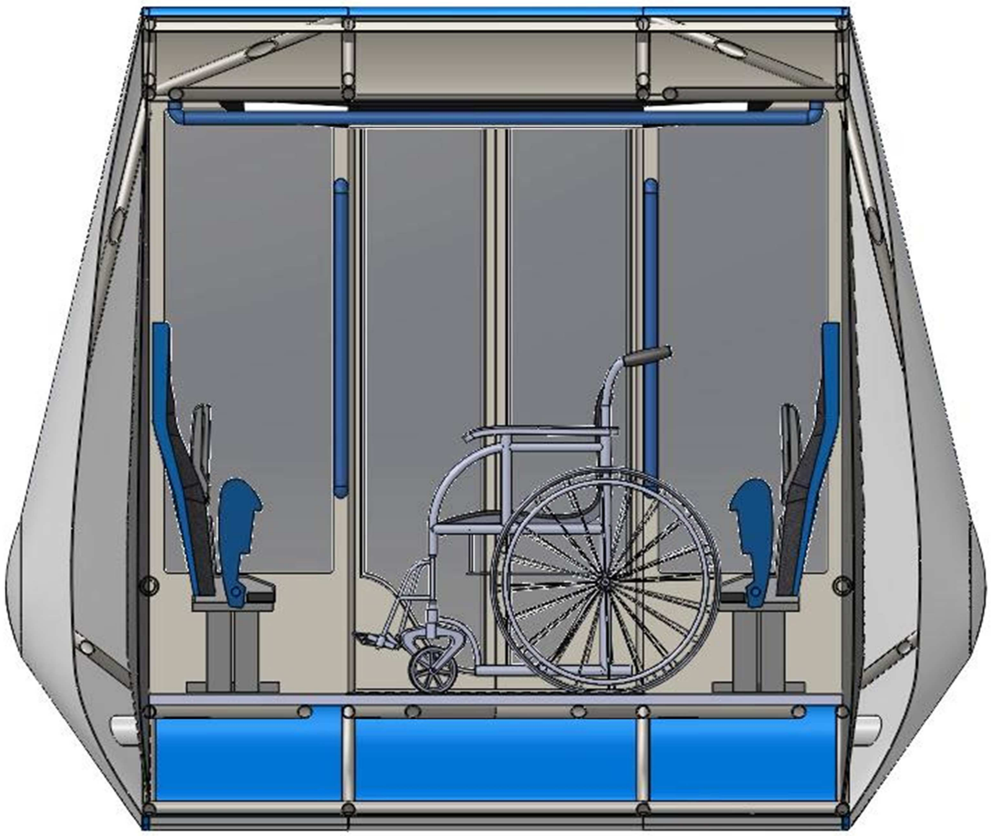


Figure 55. Side view (cross-section) of both rows of seats folded with wheelchair on one side

Figure 56. Angled cross section showing that there is ample room for wheelchair and follows ADA regulations

In addition to both ADA and federal transportation regulations, the minimum door width must be no less than 32” across. The design presented here both satisfies and exceeds that regulation by setting the door width to 34” (figure follows)

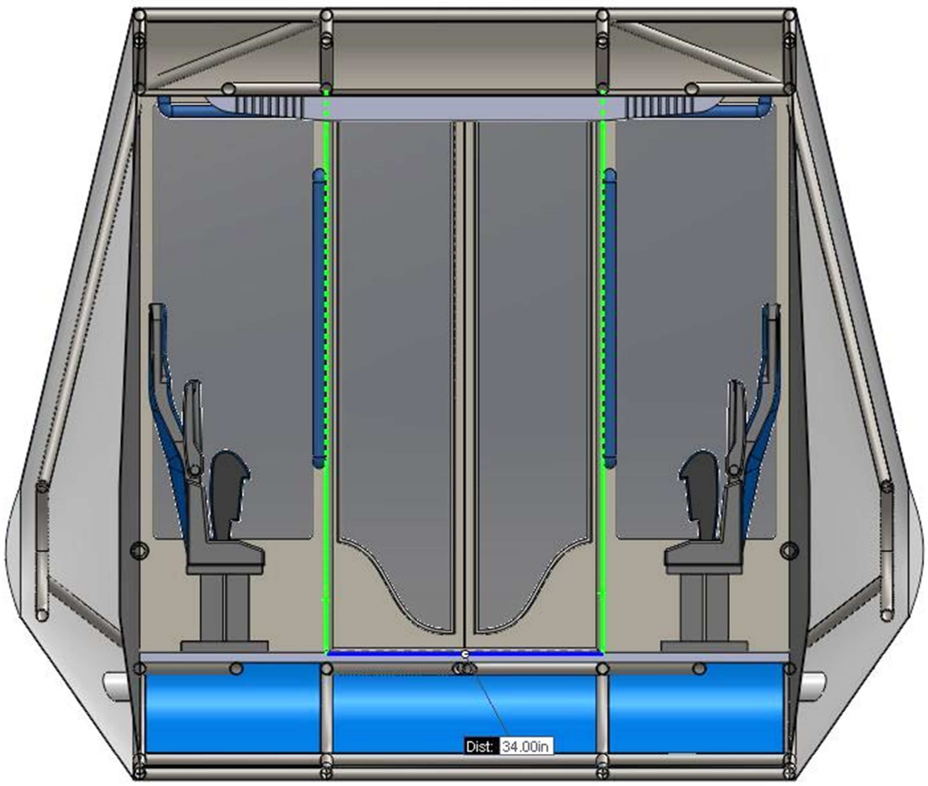


Figure 57. Door clearance is 34 inches wide

HVAC

It is important that passengers are comfortable while riding in the cabin so heat and air conditioning are a necessity. This adds energy usage that needs to be accounted for. The cabin is a unique design and therefore it makes it difficult to incorporate a standard HVAC design. Estimation can be made though as to how much power it will take.

Since the cabin is small, it does not take much power to run the air conditioning of heating unit. The total power required for one unit is 900 BTU/hr, as shown in **Error! Reference source not found.** below. To determine the power required in BTUs, the surface area is multiplied by a factor of 25. It is then converted to watts. From there estimation is made as to how often the air or heat will be on during the year and then the hours are multiplied by the watts. It takes the same amount of power if the heat or air is on so there does not need to be separate calculations to figure out when the air or heat is on.

According to the solar team's monthly energy output the total amount of solar power that can be supplied in a year is approximately 965,000kWh. This means that the total energy consumption for one car, 1155.27kWh/yr, is only about one-tenth of a percent of the total energy that the solar panels will provide so it will not have a big impact on the system.

Table 7. HVAC Energy Usage

Power(BTU/hr)	900
Power(W)	263.76
Hrs/day	12
Energy(kWh/yr/car)	1155.27

Safety

Passenger safety is always a major concern when it comes to moving vehicles. Like buses and trains, cabins also need similar safety measures.

The first thing that comes to mind regarding safety is how the structure will react when various forces act upon it, such as wind loads or just the weight of passengers. This is where the main structure of the cabin plays a part. A tube frame structure was chosen to be used due to the weight savings and ease of analysis.

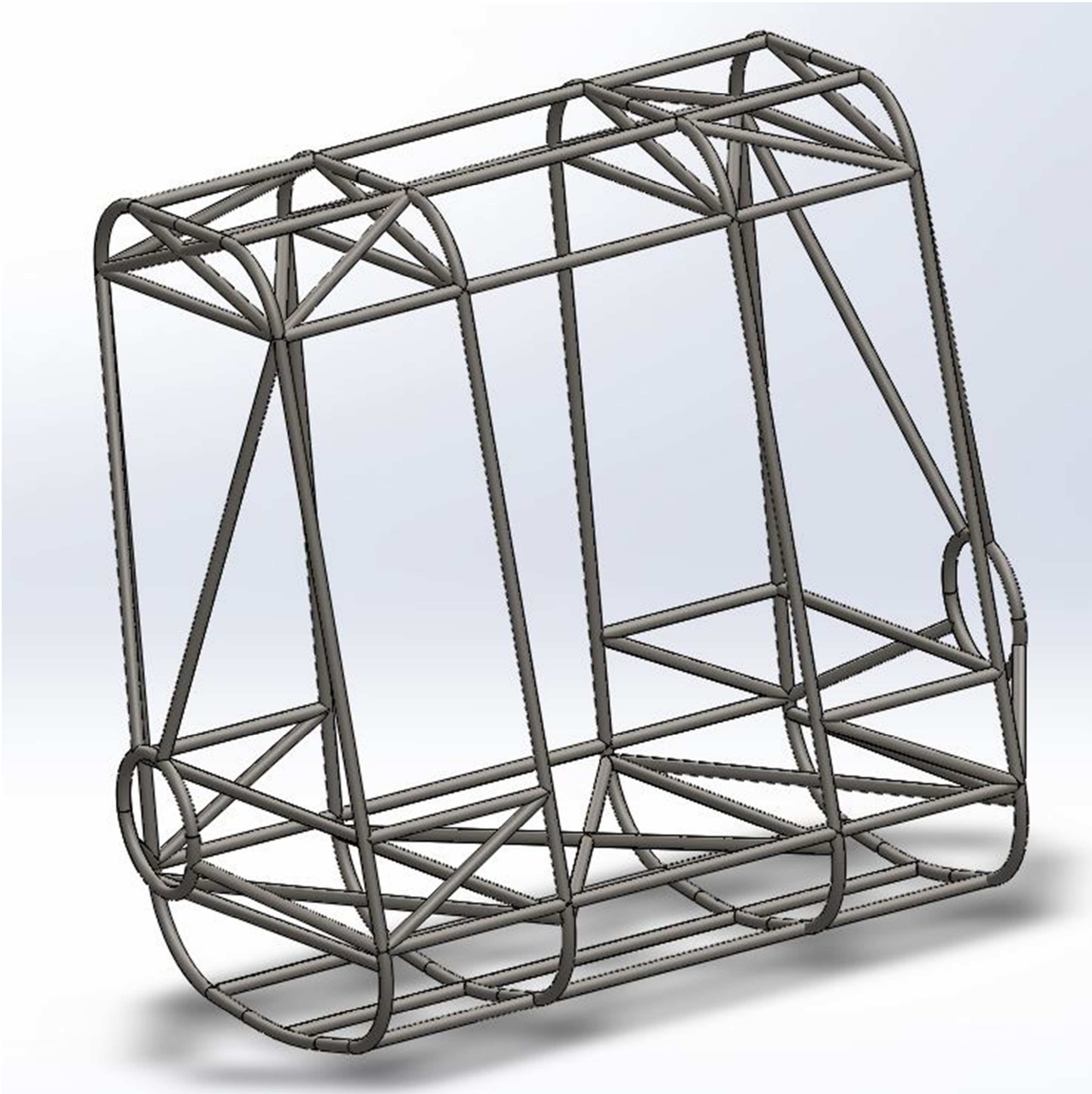


Figure 58. Frame modeled with SolidWorks (Weldments)

The frame was modeled using SolidWorks by utilizing the Weldments feature. Through this feature, a tubing size can easily be defined and changed so that different sizes can be used. Furthermore, the use of weldments in SolidWorks allows the SolidWorks Simulation application to automatically utilize beam elements instead of using solid elements. The use of beam elements not only allows the cross-section of the tubing to be easily defined, but also reduce the amount of resources required to analyze the entire structure (Beams and Trusses, 2012).

Table 8. Frame and Tubing Properties

Tubing Material	Chromoly 4130 Steel (Annealed)
Frame Tubing Size	1 ½” OD x 0.095” Wall Thickness
Frame Weight	328 lbs

As mentioned, 4130 Steel is commonly used for structural tubing in both aerospace and transportation applications due to the exceptional strength to weight ratio (Aircraft Welding and Steel Tube Fabrication, 2013). In addition, 4130 Steel can be welded easily, which is how the frame itself will be constructed.

Static Free-Hanging Full Passenger Weight Capacity Load Analysis/Simulation

This analysis shows the effects of the max load of passengers with respect to the stresses, deformation, and deflection of the frame. The analysis was done by simply simulating the cabin in a static state, which is when the cabin is not in motion. The frame should be able to sustain the static maximum load (total max passenger weight – 1000 lbs) as well as any effects from acceleration due to gravity.

Table 9. Model Data

Model Type	2-D Line
Element Type	Beam, Hollow Tube Cross-Section
Constraints	(Fixed) – All DOF fixed on the roof to simulate suspension
Loads	See **Error! Reference source not found.** for loads
Material Properties	4130 Steel
Units	Inch-lb-sec (IPS)

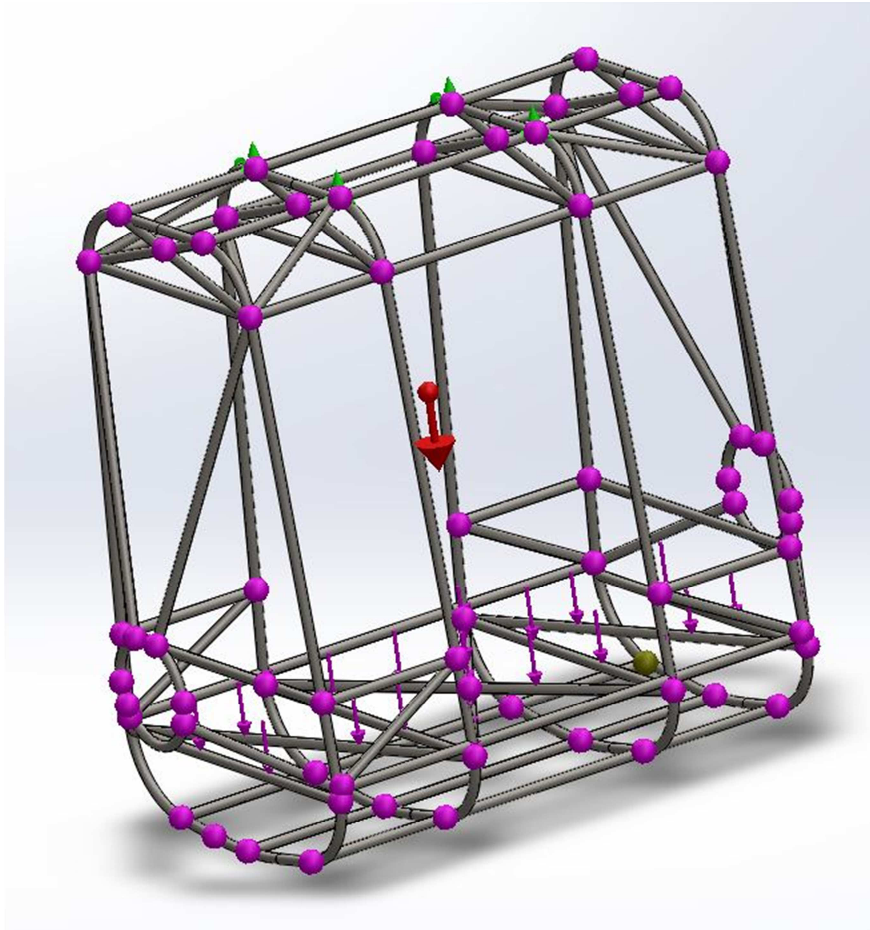


Figure 59. Loads and constraints to simulate effects of total max passenger weight on structure

The four middle joints closest to the center of the roof have all degrees of freedom fixed to simulate the frame's attachment to the bogie. A total force 1000 lbs is assigned to the beams that are supporting the floor.

Table 10. Results Summary for Full Weight Capacity Analysis

Constraint	Fixed Ends on Middle Roof Panel
Yield Strength of Material (psi)	66717.4 psi
Maximum Von Mises Stress (psi)	19950.6 psi
Factor of Safety	3.34
Maximum Deflection (in)	0.11 in
Total Number of Elements Used – 3D Beam	1731

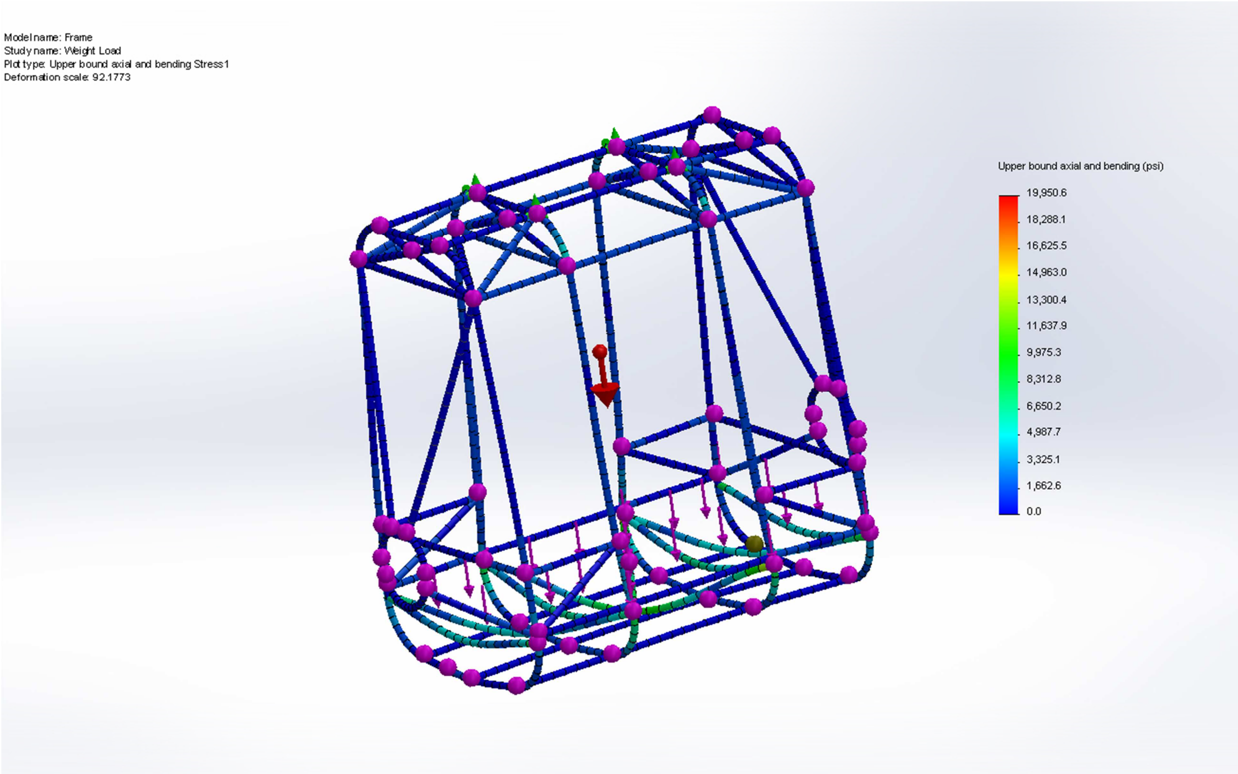


Figure 60. Plot shows Maximum Bending Stress (Highighted Red)

The maximum bending stress occurs at the joints that hold the cross members to the main part of the frame. This is due to little support below the cross member in the center of the frame. A lack of support would cause unnecessary motion and would ultimately cause the member to deform and bend, resulting in increased combined axial and bending stress. However, since the safety factor is 3.34 and greater than 1, it is unnecessary to add additional support which would add weight and need for material.

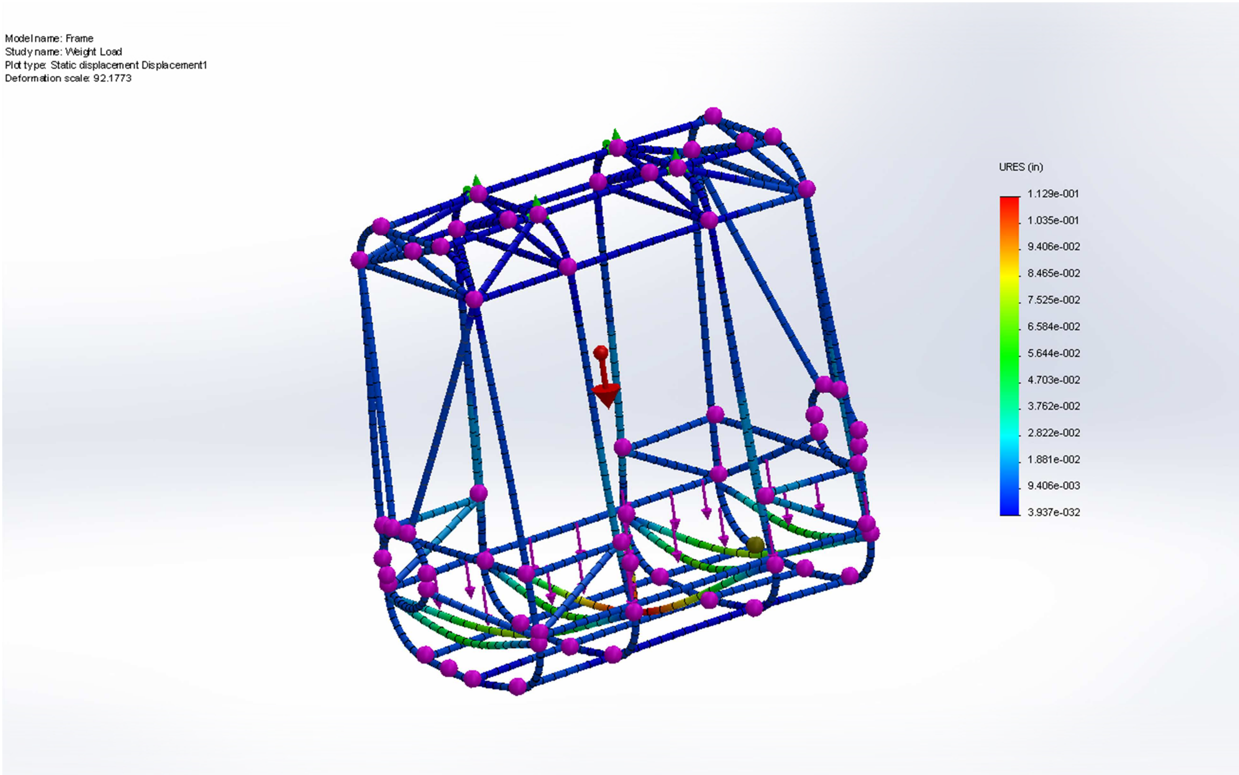


Figure 61. Maximum deflection of 0.11" at points shown in red

The maximum deformation occurs in the center of the cabin where the structural members intersect. This relatively large deflection occurs due to the longer lengths of the members compared to the members that support the seat area in combination with the amount of space in between lateral structural members (23 inches for the seat supports compared to 34 inches for the center).

Wind Load (Side Load) Analysis/Simulation

Since the cabin is suspended from the bogie, and ultimately the guide way from a significant height, wind load on the side of the cabin must be considered. The horizontal force applied on the side of the cabin due to the wind load causes the frame to translate along the horizontal plane.

For this side wind load analysis, a maximum wind speed of 55 miles per hour will be used. This wind speed was chosen as the National Weather Service considers a storm warning as forecast winds of 48 knots (55.2 miles per hour) or higher (Weather in the San Francisco Bay, 2010). For reference, the storm warning is stated to be more dangerous than gale warnings (34 to 47 knots). The wind speed must be then translated into wind force using the following equations

$$F = P * A * C_d$$

$$P = 0.00256 * v^2$$

Where P is pressure, A is the cross sectional area (95” height, 108” width), Cd is the coefficient of drag, and v is the velocity (wind speed, 55 mph) in miles per hour (Wind Force/Side Load Calculator, 2013).

The wind force was calculated to be equivalent to 602.9 lb-force.

Table 11. Model Data

Model Type	2-D Line
Element Type	Beam, Hollow Tube Cross-Section
Constraints	(Fixed) – All DOF fixed on the roof to simulate suspension
Loads	See **Error! Reference source not found.**
Material Properties	4130 Steel
Units	Inch-lb-sec (IPS)

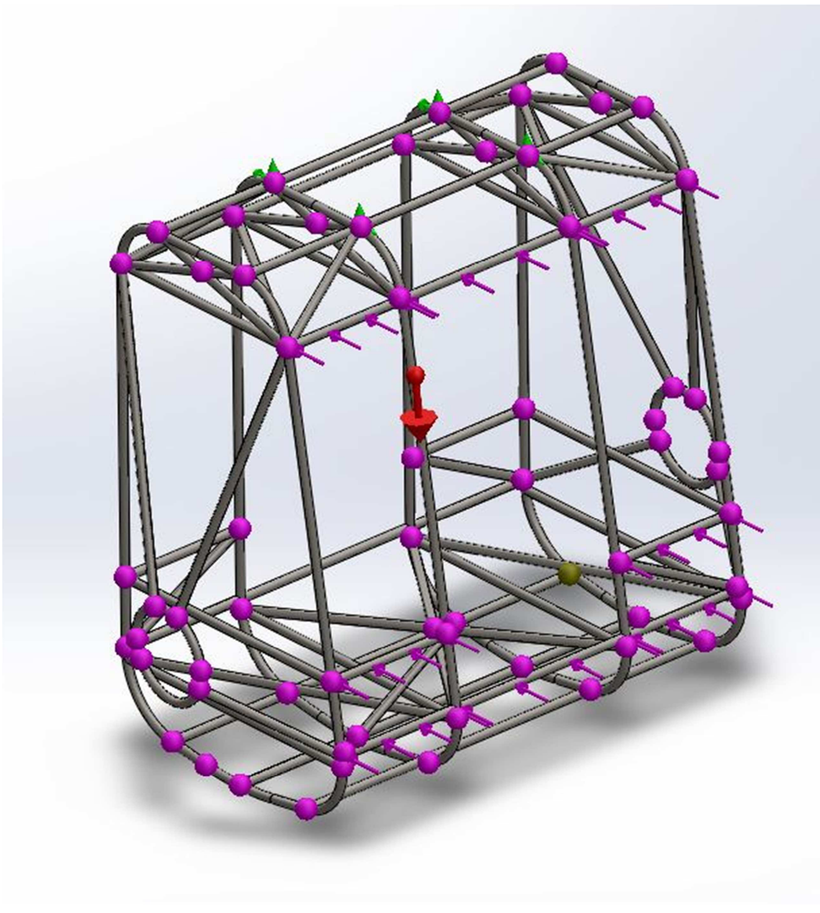


Figure 62. Loads and constraints to simulate side wind load

As seen in **Error! Reference source not found.**, the four mounting points on the roof have all 6 degrees of freedom fixed to simulate a rigid body. The wind force is applied to all the structural members on the side of the cabin to simulate a wind gust acting on it. Each of the defined forces has a direction normal to the side of the cabin as well.

Table 12. Results Summary for Wind Load Analysis (55 mph)

Constraint	Fixed Ends on Roof
Yield Strength of Material (psi)	66717.4 psi
Maximum Von Mises Stress (psi)	38432.7 psi
Factor of Safety	1.74
Maximum Deflection (in)	0.53 in
Total Number of Elements Used – 3D Beam	1731

The factor of safety is greater than 1, which allows the frame to be safe given the loading conditions and constraints of undergoing a storm level wind gust of 55 miles per hour.

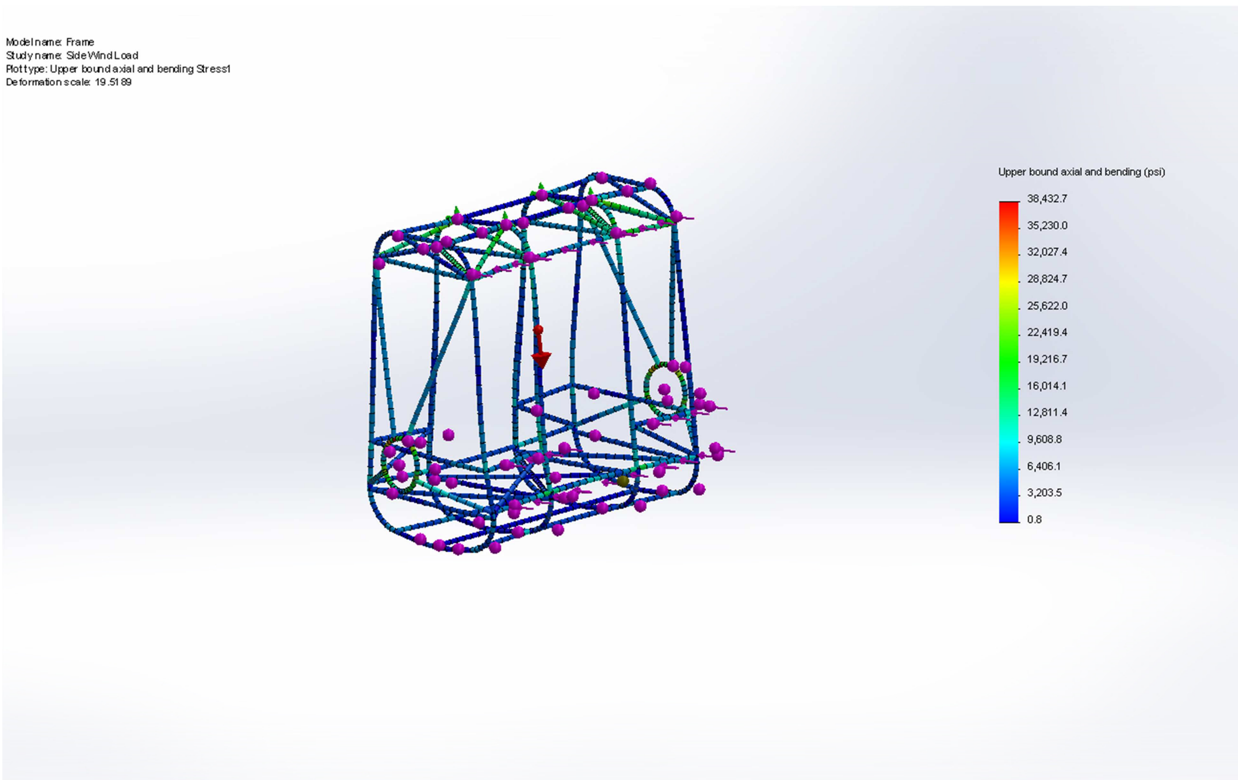


Figure 63. Plot shows Maximum Bending Stress (Highighted Red)

The maximum bending stress actually occurs at the nose reinforcement members, specifically where the ring is joined with the vertical members that are attached to the roof of the frame.

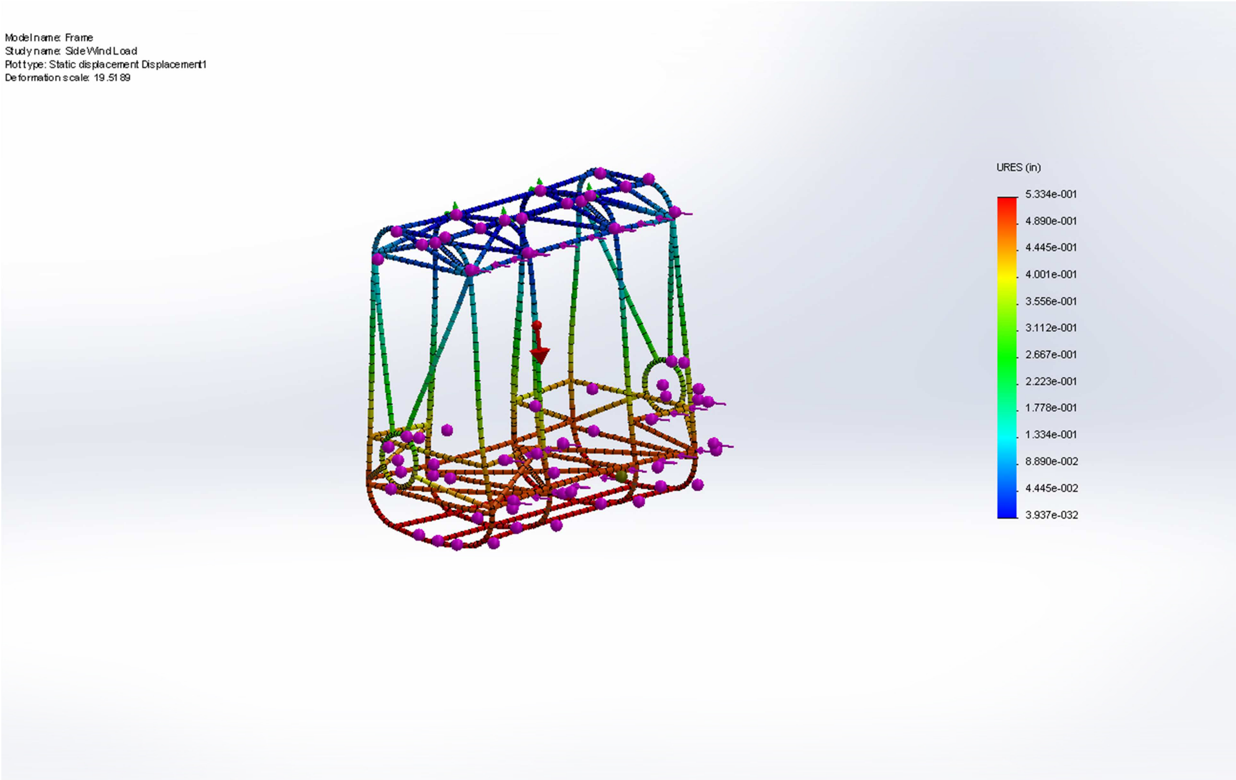


Figure 64. Maximum deflection of 0.53" at points shown in red

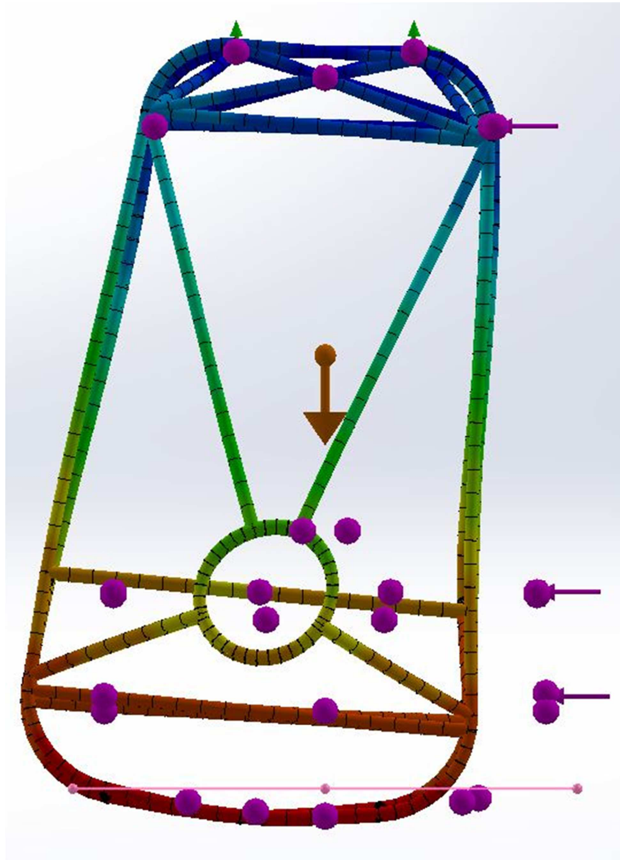


Figure 65. Front View of displacement (Deformation Scale 19.5)

The maximum deflection occurs on the underside of the cabin, in which the cabin sways along the direction of the wind force.

Error! Reference source not found. shows the front view of the deformation that is scaled up by 19.5 to exaggerate the displacement. Note how the roof remains rigid and shows little to no displacement due to the structural reinforcement members. As mentioned, the lower part of the cabin shows the maximum displacement due to a hinge-like motion caused by the wind force and the fact that the top is rigid.

A separate analysis was also done to simulate how the cabin will react under less dramatic and more normal wind conditions. A normal wind speed/gust in the San Francisco Bay Area ranges from 7.1 to 14 miles per hour and the average yearly is about 10.6 miles per hour (NOAA, 2008). Using the average, the results were found below in **Error! Reference source not found.**. The equivalent wind force was calculated to be 22.34 lb-force. As one can see, the frame will be able to handle normal wind conditions with ease.

Table 13. Results Summary for Wind Load Analysis (10.6 mph)

Constraint	Fixed Ends on Roof
Yield Strength of Material (psi)	66717.4 psi

Maximum Von Mises Stress (psi)	2209.7 psi
Factor of Safety	30.2
Maximum Deflection (in)	0.0197 in
Total Number of Elements Used – 3D Beam	1731

In summary, this analysis proves that under normal wind load conditions, the cabin's structure will remain intact and will not fail. Even in storm conditions, such as storm force wind gusts of 55 miles per hour, the frame will not fail. In addition, these analyses exaggerate the effects of the winds since they were modeled to be rigidly suspended, which is not the case. The bogie has a suspension that will reduce the effects of wind forces on the side of the cabin.

The next question to be asked is what the passengers should do in case of emergency and evacuation. Usually after a collision or emergency, the power is cut off to the cabins to prevent any additional damage. During this time, the door may or may not be closed shut; therefore, a manual door release lever must be utilized. Two fire extinguishers are placed in each cabin (one on each side) in case of fire.

Preventive safety measures are another important aspect of cabin safety. Potential injuries can be prevented by implementing some basic safety equipment. Grab bars are major safety components to prevent passenger injuries. The cabins may or may not experience large forces during acceleration and deceleration.

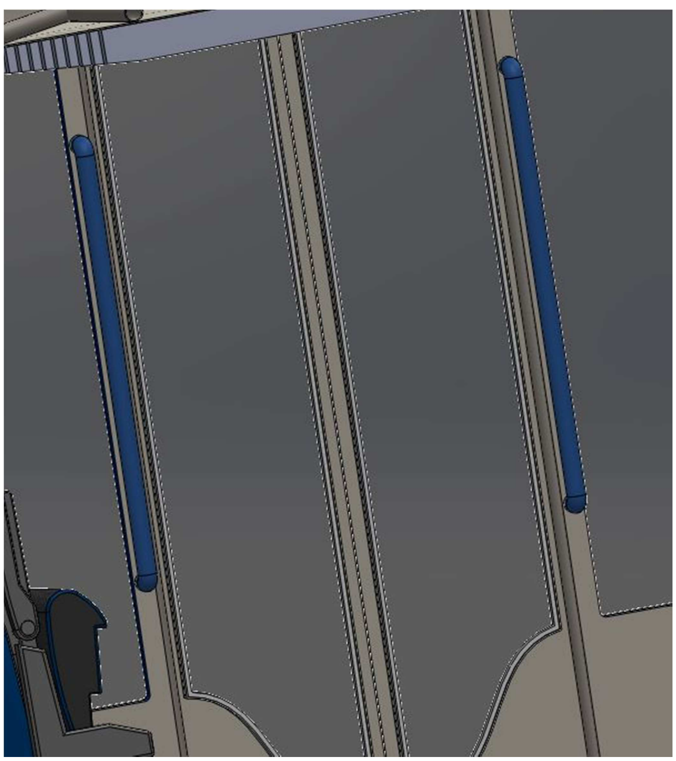


Figure 66. Vertical grab bars placed at each doorway

A vertical grab bar is placed on each side of the door since passengers tend to use them when entering and exiting the cabin, which is shown in **Error! Reference source not found.** above. Passengers also use these bars right before the cabins reach the station.

Horizontal grab bars are mounted from the ceiling on the right and left side of the cabin. The bars are mounted along the entire length, which allows passengers to stand from their seats, grab the bars, and hold onto them until they grab the vertical bars near the doors.

Rubber mats, shown in **Error! Reference source not found.** below, are placed on the floor in front of the doors to decrease the risk of passengers slipping. The mats have ridges which allow for maximum grip under slippery circumstances.

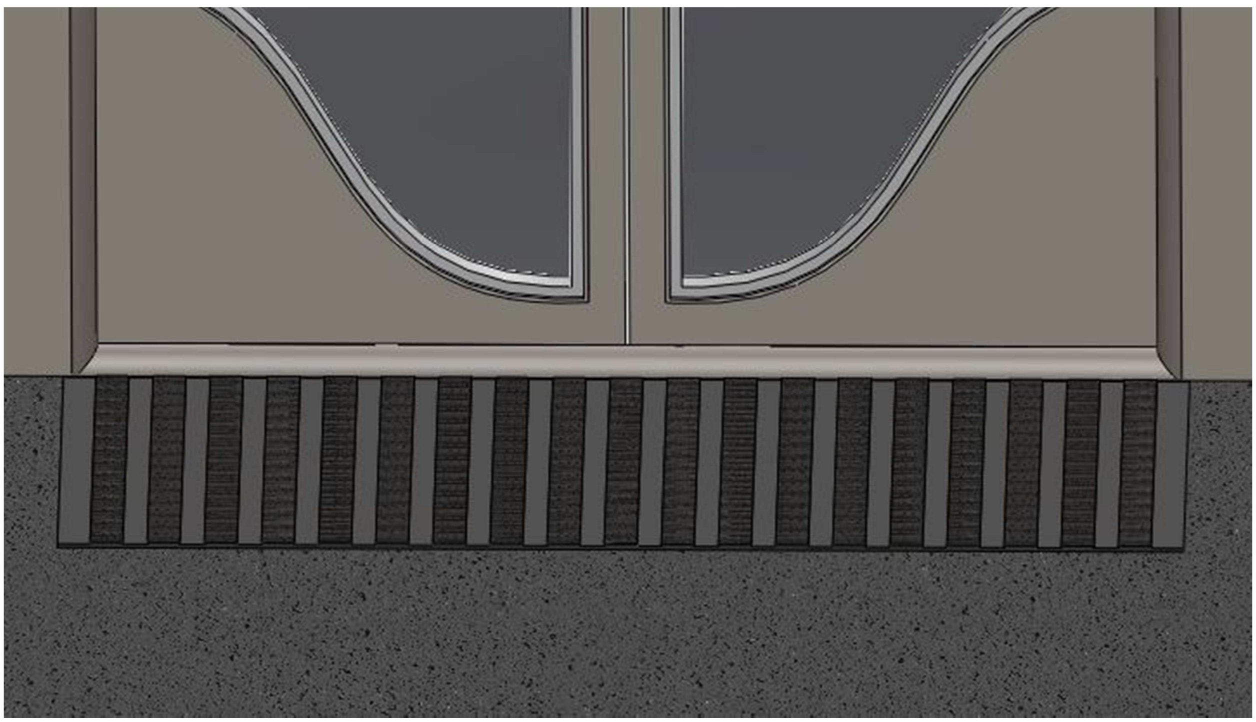


Figure 67. Rubber mats placed in front of doorways to prevent slipping

Propulsion

Propulsion Bogie Design

The propulsion team's task for specifying bogie design began with deciding the method of propulsion that the personal rapid transit system would utilize. After weighing the options, the SMSSV team settled on linear induction motors as the method of propulsion. With this in mind, the propulsion team was then tasked with designing a bogie that would incorporate the technology of linear induction motors with the pod car design of the cabin design team.

Although the intent of this design was to create a simple bogie unique to previous designs, there are of course elements of the design that mimic existing systems. Because of this, the bogie design presented below is a culmination of past, present, and new ideas. The bogie design incorporates many different elements, each with their own function, in order to provide a complete system that allows smooth and efficient movement of the PRT. These individual elements will be explained in detail below.

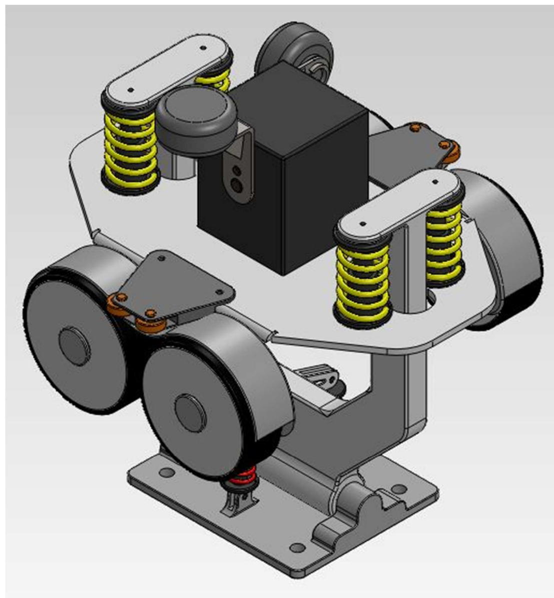


Figure 68 Isometric view of the complete bogie design

Chassis

The chassis, or frame, was designed to provide sufficient strength and rigidity to the bogie. These factors were incorporated into the design to ensure stable and safe travel at higher speeds. As can be seen in the figures below, the chassis measures 48 inches long by 52 inches high and is a total of 43.5 inches wide.

There are two main portions of the bogie's frame. The center support which holds the wheels, guides, and propulsion system is made from ¾ inch steel with two large opening that allow the second support to move freely through. This second support, which is a 3 inch wide boxed frame, is connected to the first by four large shock towers which suspend the Cabin only 16 inches from the bottom of the bogie's wheels. The cabin is suspended by means of four large fasteners which affix it to the "swinging" lower platform of the bogie. This platform is connected to the second support by a large bearing that allows the cabin some movement side-to-side which is important in maintaining passenger comfort throughout turns.

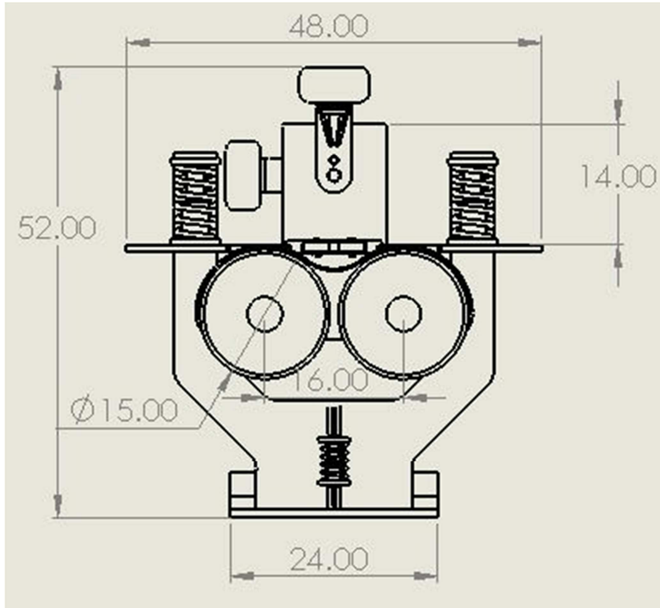


Figure 69 Side View of Bogie with Dimensions

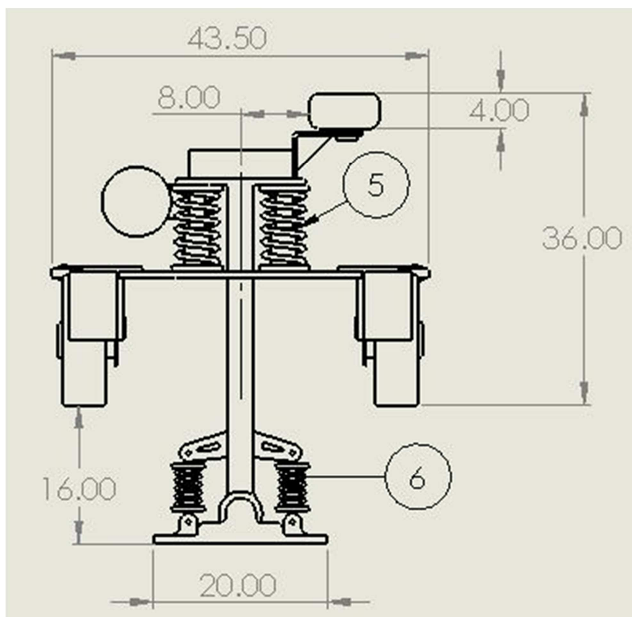


Figure 70 Front View of Bogie with Dimensions

Also seen on both sides of the bogie are two "guides" that prevent the bogie from unnecessary horizontal travel while running on the guide-way. These guides consist of two small wheels held by a support that is then mounted to the chassis. The wheels are somewhat malleable in order that they may be tough enough to withstand their constant interaction with the sides of the guide-way.

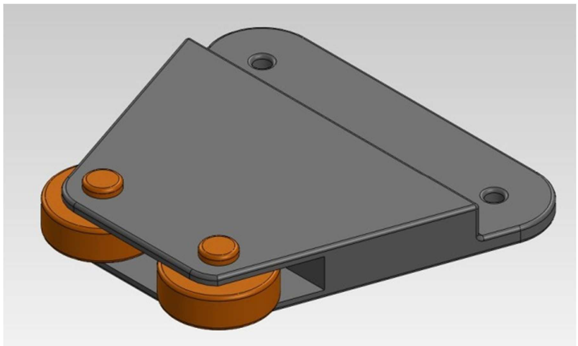


Figure 71 Bogie guide located on both sides of the chassis

Wheels

The wheels for this bogie were designed to be strong enough to support the weight of the PRT system, yet small enough in diameter to provide a tight turning radius. An added benefit of the wheel diameter selection was its careful balance between high speed and ease of acceleration. Too large of a wheel and the amount of torque needed to accelerate would exceed this system's capabilities, while a wheel diameter that was too small would result in lower top speeds and dangerous wheel RPM's.

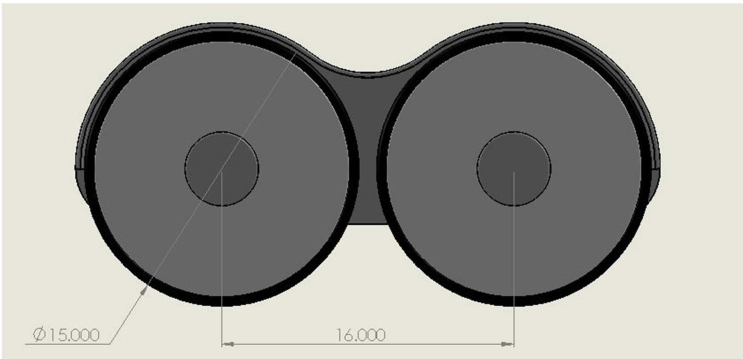


Figure 72 Wheels and wheel-housing used on the bogie

The wheels measure 14 inches across and their centers are 16 inches apart. This relatively small wheel size combined with the closeness of their centers allows for a tight turning radius. Wrapped around the wheels is a rubber tread which adds an extra inch to the overall diameter and provides extra friction necessary for safe and consistent acceleration and stopping of the PRT. Even though the tread wears quicker than a solid steel wheel, it is much cheaper to replace and thereby increases the longevity of the wheels.

Suspension

The propulsion team's bogie design utilizes a unique suspension system that serves to improve both system performance and consumer comfort. Vibrations and disturbances may occur due to unknown or unpredictable sources, resulting in catastrophic oscillations if uncorrected. Not only does the suspension system of this bogie counteract vibrations and unwanted oscillations, it also provides a buffer between the vertical movements of the bogie from the cabin's occupants.

The suspension system designed for this bogie implements custom vertical damping in order to maximize comfort and stability. Combined with this are two more damping systems to provide stability to the cabin throughout turns. By allowing, yet controlling this "side-to-side" motion, the cabin is given some freedom to tilt during cornering, resulting in a more comfortable ride for the passengers.

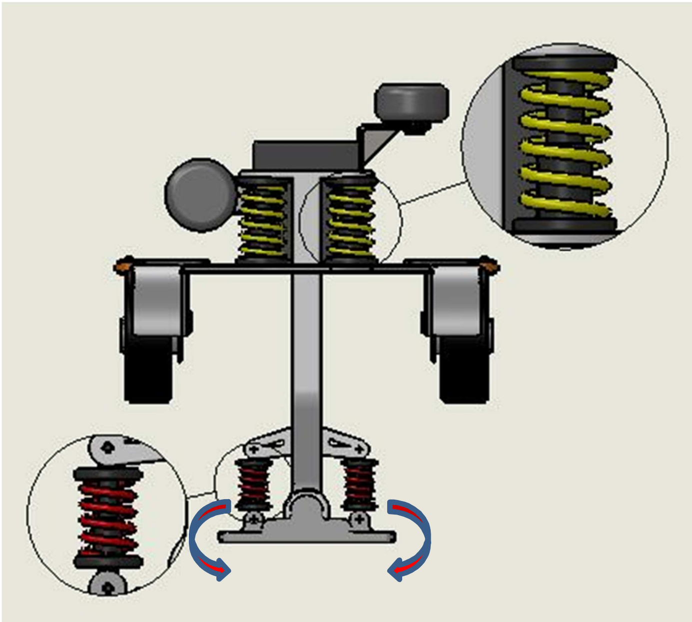


Figure 73 Detailed view of suspension components & visualization of bogie's motion

The larger springs are 10 inches tall (uncompressed) in order to provide enough travel in the event of large gaps or inconsistencies in the guide-way. The smaller springs which control the radial movement of the Cabin are only 6 inches tall (uncompressed) and are much smaller in diameter. They are much smaller due to the fact the radial movement is not expected to be great considering the top speed of the system was determined to be 50 mph.

Switching Mechanism

This bogie's switching mechanism features two separate guide wheels to dictate the path of the bogie during track changing. This switching mechanism's supports can be radially manipulated, individually, to guide the bogie off the main track for station integration. A similar switching mechanism is used on Taxi 2000's bogie, which is where this design concept originated. (http://www.taxi2000.com/) Further literature on the original design can be found within J. Edward Anderson's patent (US4522128).

The features or "guides" extruding from the top of the guide way (seen in figure below) are placed just before, during, and after guide-way interchanges. These guides correspond to a direction the PRT will head once the switching mechanism makes contact with it. Contact between the right guide and the right wheel sends the system to the right and vice versa.

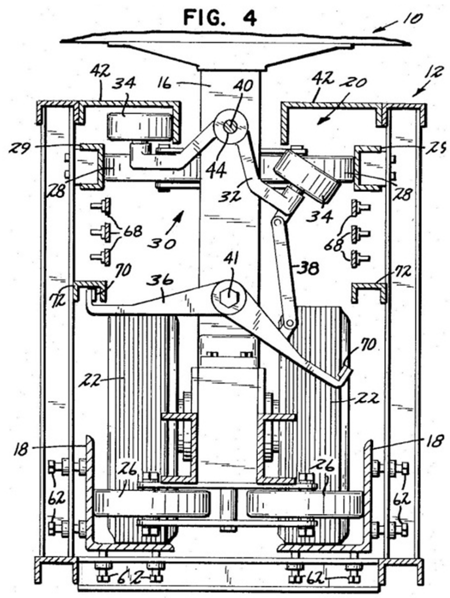


Figure 74 Cross-section view of taxi 2000 proprietary switching mechanism (Anderson 1985)

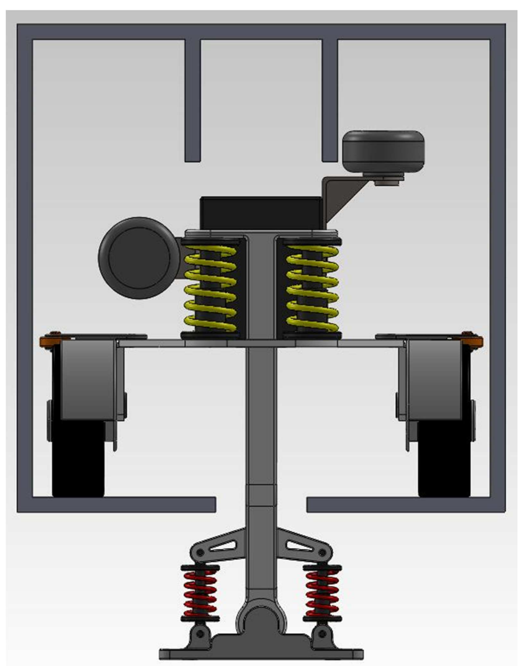


Figure 75 Cross-section view showing interface between guide-way and switching mechanism

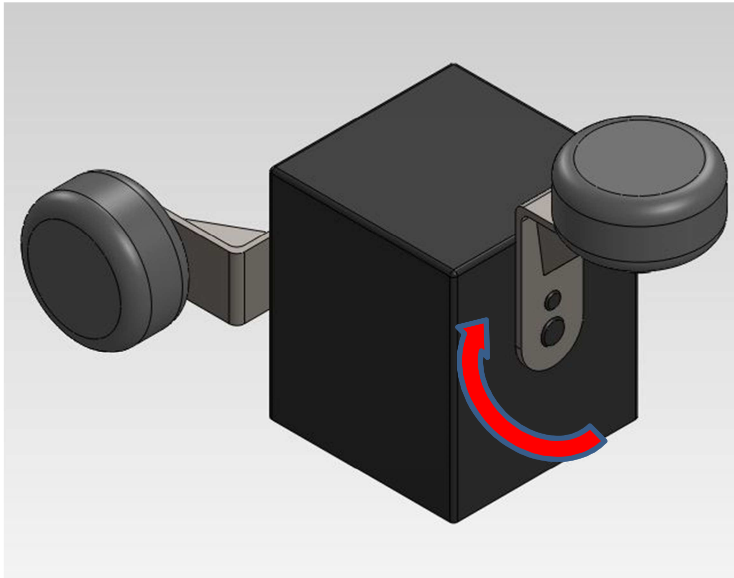


Figure 76 Visualization of Guide-wheel support movement and interface with bogie

The switching mechanism is physically made up of two simple, independent guides that each supports a large wheel. Each of the guides is mounted to the bogie and is radially controlled by means of a simple motor (not seen in figure). The guides are placed on the sides to prevent them from interfering with the LIM propulsion system.

Stress Analysis

An important step in any design, especially one intended for commercial use, is to perform stress analysis on critical structural elements. In doing so the designer is able to determine which elements may need additional support or strengthening and where others may be optimized by reducing material in key locations.

For the bogie, it was decided to perform stress analysis on two of the main load-bearing elements using PTC's FEA application "Mechanica". These two elements are the central portion of the chassis upon which the wheels and secondary chassis are mounted and the guide-wheel supports. It was decided that these two elements be analyzed not only because they are the thinnest, but also because they are subjected to the most severe loads throughout the bogie's operation. An important assumption was made that the outcome of the stress analysis of these parts would determine the need to perform further analysis on other elements of the bogie. If these critical parts did not fail, then it is assumed that no other parts would fail.

For the central portion of the chassis, constraints were placed on the holes in which the bogie's wheels are mounted. The weight of the entire system, including the loaded cabin, was simulated by placing a 3500 pound force upon the top of this central chassis. These constraints and applied loads simulate the forces the part is subjected to.

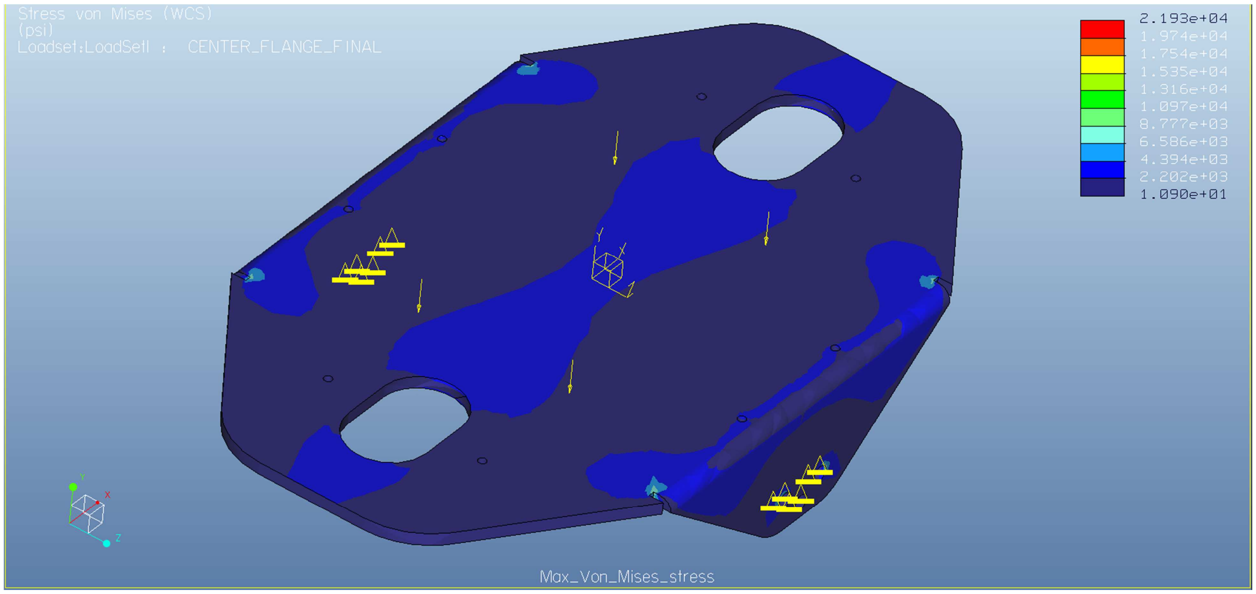


Figure 77 Central Chassis Fringe Plot showing maximum vonMises stresses

For the guide-wheel support, the entire back portion of the support is constrained and a load of 7000 pounds is applied to the hole in which the guide-wheel is mounted. The back side of the support was fully constrained to simulate its contact with the portion of the bogie it is mounted to. A load of 7000 pounds was applied to simulate the maximum force the part would be subjected to during a turn.

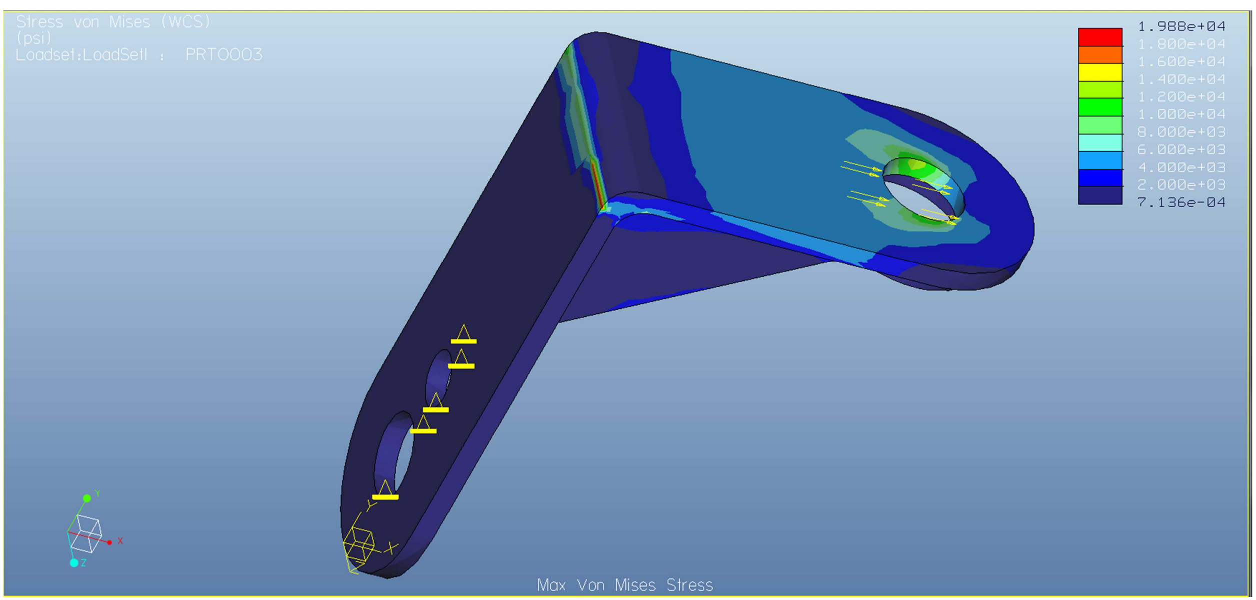


Figure 78 Guide-wheel support fringe plot showing maximum vonMises stresses

As can be seen in the fringe plots shown in the figures above, both the central portion of the chassis and the guide-wheel support are capable of withstanding these forces and have a safety factor over 3.

Quantitative results from these analyses are given in the tables below.

Table 14 Results of Central Chassis stress analysis

Part Analyzed	Central Chassis
Material	4130 Steel
Yield Strength of Material	6.67E+04 psi
Max vonMises	2.193E+04 psi
Safety Factor	3.04

Table 15 Results of guide-wheel support stress analysis

Part Analyzed	Guide-wheel support
Material	4130 Steel
Yield Strength of Material	6.67E+04 psi
Max vonMises	1.98E+04 psi
Safety Factor	3.36

Structure and Guide Ways

Since the Superway will be a suspended system, it will be required that the structure be high enough to safely accommodate the podcars and the on ground objects such as cars, trees, street signs, and pedestrians. Therefore, sufficient space for safe grade separation will be considered when designing the structure. The required clearance between the bottom of the podcars and the ground surface will be maintained above 14 ft based on AASHTO standards for highway clearances. More specific requirements for the structure are presented inChapter 6 (page 33). Those requirements are discussed in more detail in the following section of this report.

Table 16. Design Specifications

Design Aspect	Specification
Clearance between grades	14 ft
Max sagging of guide way	1 in.
Max swaying of guide way	1 in.
Span length	100 ft
Type of foundation	Deep foundation with precast concrete piles.
Type of steel for columns	A574 grade 50
Type of guide way	Pratt truss

Foundation Design Requirements

The structure required for the suspended PRT system will mandate the use of deep foundations. This type of foundation should be able to hold the bending moment created by the weight of the cabs hanging at a certain distance away from the center of the columns. Deep foundations consist of a pile inserted deep into the soil layers. The pile transfers the vertical loads of the structure to the soil by the contact friction created between the soil and the surface of the pile as shown in **Error! Reference source not found.**(a). In addition, the piles also transfer the horizontal loads such as those due to wind and earthquakes to the surrounding soil as shown in **Error! Reference source not found.**(b). **Error! Reference source not found.**(c) shows the ability of the piles to also transfer the bending moment into the surrounding soil by exerting a lateral pressure into the soil.

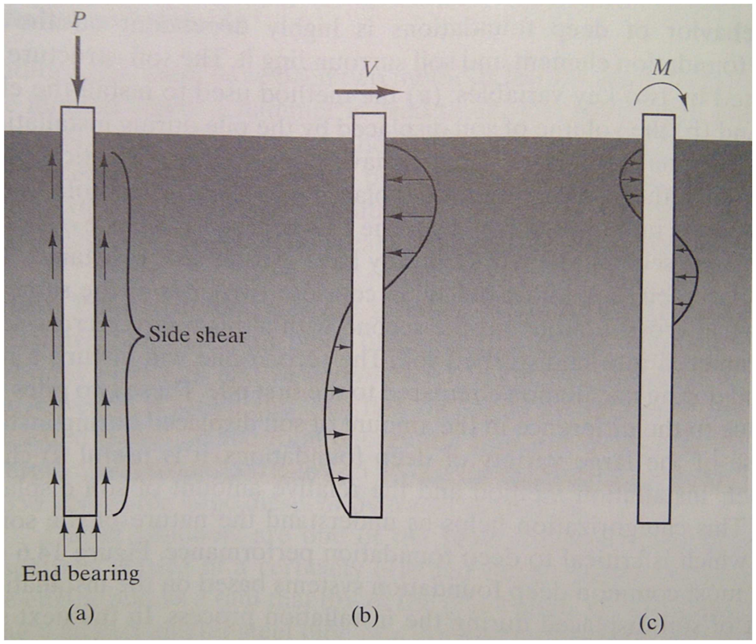


Figure 79. Transfer of column load to soil in typical deep foundation (Coduto, Yeung, & Kitch, 2011)

In general, concrete piles are divided into two categories: (a) precast piles and (b) cast-in-situ piles. Precast piles are typically 10 m to 15 m long and have an approximate load of 300 kN to 3000 kN (67 kip to 675 kip). Some of the advantages of precast piles are: they can be subjected to hard driven, they are corrosion resistant, and they can be easily combined with a concrete superstructure. However, their disadvantages include the difficulties of transporting them and achieving a proper cutoff (Das B. , 2011). The Superway design team is considering modular construction as a way of minimizing the levels of disturbance during the construction phase. Therefore, precast piles were found to be the most appropriate type of piles to use for the foundation.

Selecting the type of pile to be used and estimating the necessary length are fairly difficult tasks. The length of the pile has to be calculated based on the type of soil, how deep the bed rock is, and how much bending moment the foundation will have to resist. Due to the existing moment at the base of the columns, the foundation design requires a complex math analysis which at this moment is not very well understood by the structures design team.

Columns

In designing a safe and efficient column, the following was considered:

1. The goal of the project is to have a structure that is efficient in construction, is environmentally friendly, and prioritizes passenger safety.
2. The columns should be designed as modular as possible to minimize disturbance during the construction phase.
3. The columns should elevate a single track system in order to suspend the podcar.
4. Columns must have minimum size and weight.

5. Minimum span length (distance between columns) must be 100ft.
6. Minimum height of the column is 28ft. to provide the 16ft. clearance.
7. Minimum length of supporting arm is 3ft.
8. The columns must be designed for a long life under variable vertical, lateral and longitudinal loads that can reasonably be expected. (Wind, rain, snow, maintenance, earthquake, impacts, etc.)
9. There can be no passenger injuries due to collisions of street vehicles with support posts, falling trees, etc.
10. The guide way must be easy to erect, change, expand, or remove.
11. The design must permit to expand indefinably.
12. The design must provide vibration damping.
13. Maximum allowable deflection is span / 800. (in our case it is 1.5 in)

In order to satisfy the requirements mentioned above, the following measures must be taken:

1. Pieces should be prefabricated at one location, then carried and assembled at the construction site.
2. Steel Gr 50, which is wide spread type steel, should be used for the project. (Steel type: Carbon, ASTM Designation A592 GR 50, provide Fy=50 ksi , and Fu = 65ksi). Steel is 100 % recyclable (regardless of the amount of energy required to be recycled), the weight of the structure would be lighter compared to a concrete structure that provides the same strength, and steel allows for quick on site repair.
3. To support the huge loading at a height of 28 ft., none of the common cross-sections could provide satisfactory results. Therefore, a built-up cross section is considered.
4. In constructing the built-up member (column), a common cross section was used in order to decrease costs and issues regarding fabricating new cross sections. This cross section can withstand the various load cases that were mentioned earlier.
5. In designing the built-up member, (column) flexibility is considered, translating that connections are made such that the member can easily be removed and rearranged.
6. One size of welding is considered to fabricate the built-up member, making fabrication faster and easier.
7. The built-up member can easily be strengthened or weakened by adding or eliminating cross sections.
8. The built-up member (column) will support the arm, and the arm will support the guide way.
9. Due to the base capacity of the columns, there can be a wide range of arm lengths, which allows for a flexible design.
10. The arm can be attached to the guide way such that vibrations created by the podcars are damped. To achieve this, rubber can be applied to the connection joint bearings.
11. Built up member will provide higher values of stiffness, resulting in less deflection from lateral forces (from the impact of heavily loaded trucks to a large earthquake).

The following assumed load conditions were considered:

- The assumed dead load is 10 kips.
- The live load assumed based on fact that each column shall responsible to carry 3 podcars in one instance. (3 x 3kips = 9 kips of live load) Impact load of 20 kips (accident of

heavily loaded truck) at height of 4ft. is considered.

- Earthquake load of 5 kips.

The initial design of the built up member was done by hand, and the hand calculations were analyzed with computer software in order to achieve a higher level of assurance. The cross section of the built up member can be seen in Figure 80, and the dimensions of the built up member are shown in **Error! Reference source not found.**.

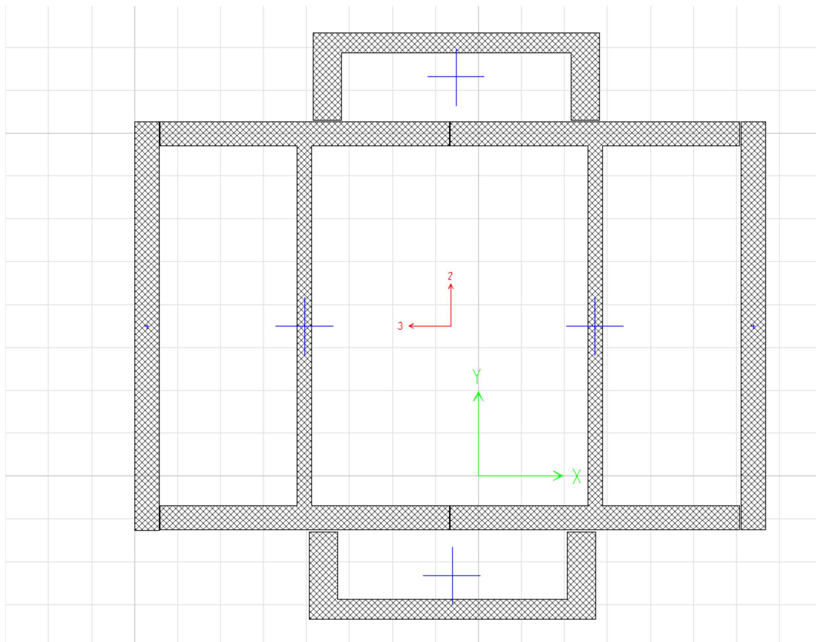


Figure 80: The built up member cross section

Table 17.Dimensions of Constructing a Built Up Member.

Items	**Cross section**	**Number**	**Weight(LB)**
W-Shape (I-beam)	W14x87	2	4872
Channel	C10x30x25x20x15.3	2	1680
Plate	14.3x0.855	2	2139

A computer analysis was done with SAP 2000, Figure 81, and the results can be seen in Table 18. The results show that with the proposed design specifications, the built up columns will have negligible deflection based on our assumed loads.

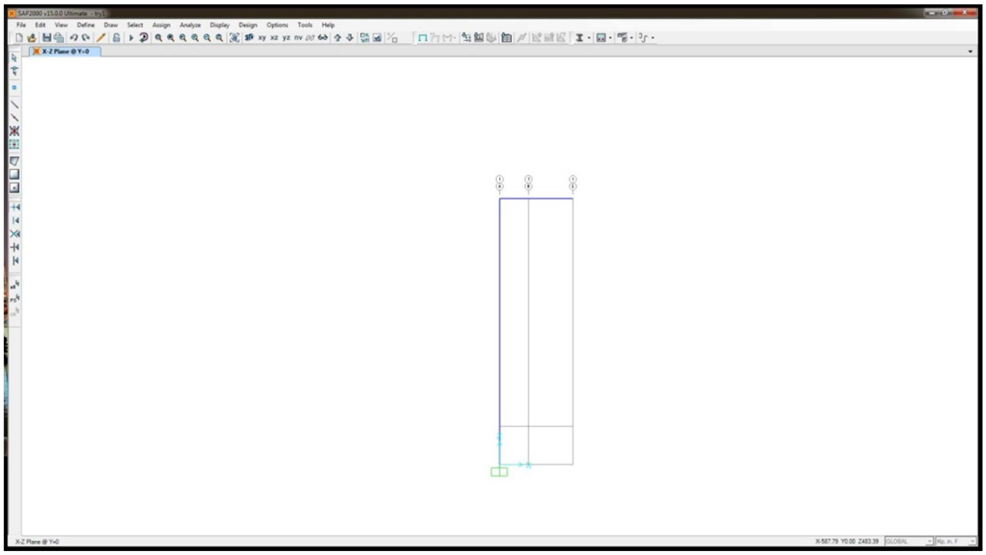


Figure 81. SAP 2000 model of a built-up member (column) and arm.

Table 18. Deflection of free edge of the arm under various load cases. U1 presents in the right direction/x axis. U2 is directed perpendicular to the page/y axis.U3 presents in the vertical direction/ z axis. A negative sign applies to the opposite direction

Loads Def.	DL	DL+LL	DL+LL+EQ	ACC+DL + LL
U1	0.41 in	0.89 in	1.05 in	0.99 in
U2	0	0	0	0
U3	- 0.34 in	- 0.67 in	- 0.62 in	- 0.69 in
R1	0	0	0	0
R2	0.004	0.008	0.007	0.00843
R3	0	0	0	0

For this analysis, the values of moment of inertia and cross section areas were tabulated from AISC manual 13th edition. The design was based on LRFD load factors. These factors and load combinations are adapted from ASCE standard (ASCE/SEI 7-10) Minimum Design Loads for Buildings and Other Structures. Greater detail of this design and estimated cost of the built up structure alone can be seen in the Appendix.

Given the acquired data, a preliminary full scale column was design, **Error! Reference source not found.**. This simple concept incorporates not only a safe and efficient column, but also a slanted surface to support the solar panels on top of the structure. The angle of the surface can be varied depending on ideal angle of tilt for maximum solar power harvesting considering the demands at any location. The connection provided by the slanted rod will also serve to strengthen the offsetting circular rod. In addition, the height of the columns can be increased or decreased for passenger comfort along uneven terrains.

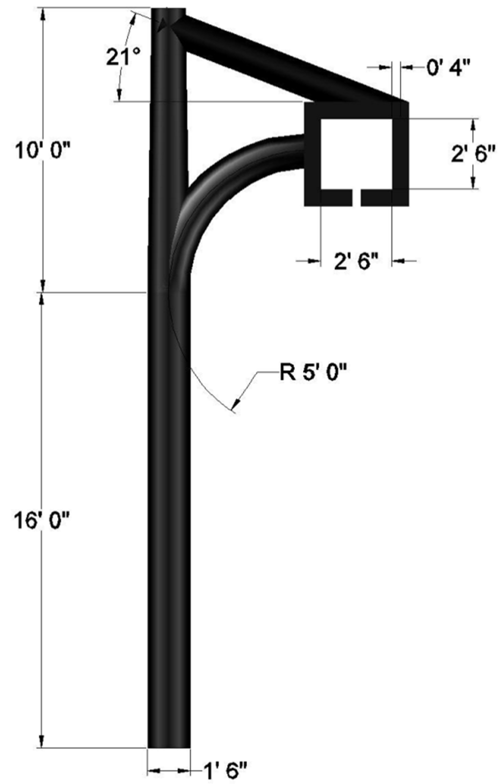


Figure 82. Column Design Preliminary Concept.

This column design concept will also allow the guide way to expand and contract due to thermal expansion. The isometric view of the columns, shown in Figure 83, gives a better perspective of the shape of the guide way. The rectangular guide way will be accommodated inside the rectangular cross-section without making a complete connection between each of the two sections of guide way. Therefore, they will be allowed to freely slide back and forth inside the rectangular sleeve without compromising the integrity of the structure.

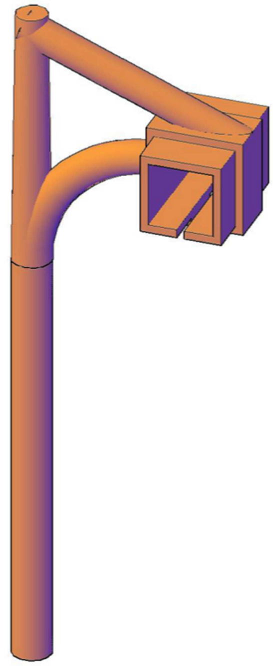


Figure 83. Isometric view of columns

Steel will be also considered as the design material for the guide way since it provides more strength than concrete for an encapsulated guide way system. **Error! Reference source not found.** shows a preliminary design concept for the guide way at an intersection. Depending on the height of the switching mechanism, the guide way will hook onto the wheels of the mechanism and guide the bogie towards the desired direction. The grooves shown in Figure 84 exist at intersections, and won't be an issue during the straightaway sections in terms of vertical movement. Additionally, the guide way will be designed to be rigid enough so that sagging doesn't surpass more than one inch when fully loaded. In addition, the space between columns will be kept between 40 and 50 ft. depending on the requirements of the location.

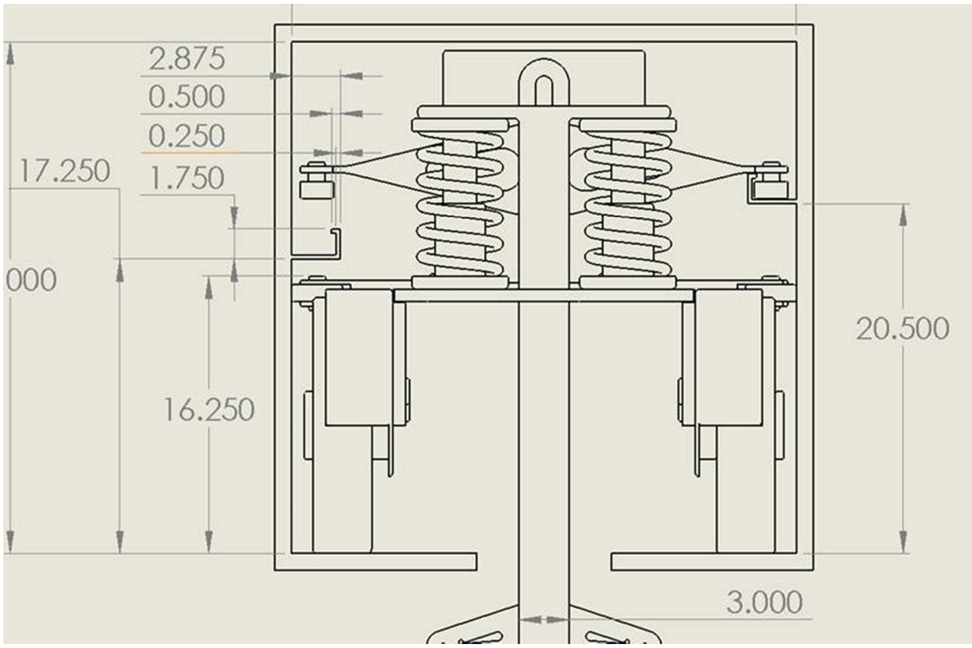


Figure 84. Guide way design preliminary concept. Switch mechanism is at required height to hook onto right groove, guiding bogie towards the right.

The design team has also considered using a Pratt truss, shown in Figure 85, for the guide way between two columns. A preliminary computational analysis on this truss was performed to calculate the axial forces of each of the members created by the live load created by the cabs. To prevent corrosion and other problems created by weathering, the truss must be covered with a certain material for which more research will be required.

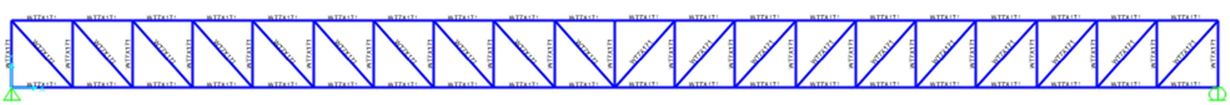


Figure 85. Pratt truss for guide way.

Visual Impact of the Structure

The preliminary design of the structure was made so that a friendly integration with the already existent infrastructure is obtained.Figure 86 and **Error! Reference source not found.** depict the structure's incorporation into the city environment. The visual impact created by the structure is minimized by the height of the structure and the slim columns.

Figure 86. Representation of the integration of the structure into a city environment. This virtual image depicts the aesthetics of the structure of the guide ways and columns, which minimizes the visual impact due to the height of the structure and the slim columns.

Figure 87. Depiction of the Structure's Visual Impact in a City Environment. This virtual image gives a ground view perspective on the minimal visual impact of the structure.

Station

High Traffic Stations

For a linear station, a pod pulls up to the station and unloads and loads passengers. If the pod in front of it has passengers that are taking their time with boarding, then that pod and all pods behind the front pod that is holding up traffic cannot continue on their journey until that pod moves. This results in congestion in the station, increase travel time, and poor customer service.

Angle berth stations were designed to address the solution to the example given above, which were talked about in the literature review section. A pod would pull into a berth and unload and load passengers, back up and then continue on with its journey. This design allows pods to bypass other pods at the station, decreases travel time and improves customer service. The main issue with this configuration for high traffic station is that a pod backs out into oncoming pod traffic, which increases the chance of collusion.

Figure 85 below addresses the issue of pod congestion for high traffic stations. A pod leaves the mainline and decelerates towards the station. Once it has reached the station, the pod would enter one of the open angle berths and unload and load. Then instead of backing up, which is done with current angle berth stations, the pod will merge onto a sub-line and accelerate back to the mainline. This design eliminates the complication which arises when backing up into oncoming traffic, solves congestion issues that can occur in high traffic stations, and decreases travel time.

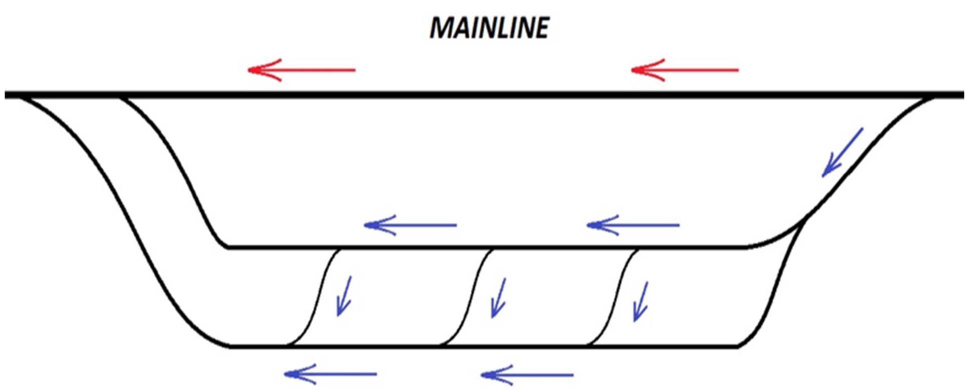


Figure 88: Configuration for high traffic flow station

This design is more costly than a simple angle berth or linear station since additional guideway is needed. This drives up the starting cost and increases the maintenance cost, but these are trade-off are important for passenger safety and customer satisfaction.

Medium Traffic Stations

Even though the angled berth design is not very practical when dealing with high traffic stations, they are ideal for medium to low traffic stations, when there is less than one pod car being called every minute. PRT systems that are fully operational currently use angle berth stations are Heathrow Airport and in Masdar City. According to an article in the Huffington Post, Heathrow Airport currently runs 21 pods, traveling from Terminal 5 to two different parking structures. The angle berth station design is ideal for this terminal because the system only has three stations, the terminal and two parking structures. The angle berth station presented in Figure 15 (page 25) would work for this PRT station design. Adding addition angle berth is not difficult, which makes this design practical for medium and low traffic stations.

Station Layout

Shown in the following figure is an angle berth station layout. The rider enters the station down by the kiosk, purchases his or her ticket and then goes to the nearest open pod. The rider then scans his or her ticket and boards the pod. Since the pod utilizes a double door design, people exiting the pod exit from a different side than the people entering, creating a steady flow of traffic not only in and out of the pod, but also within the station. The red line shown represents where a barrier of sorts, that being hand rails or a small wall, to prevent people from disrupting traffic follow in another pod berth.

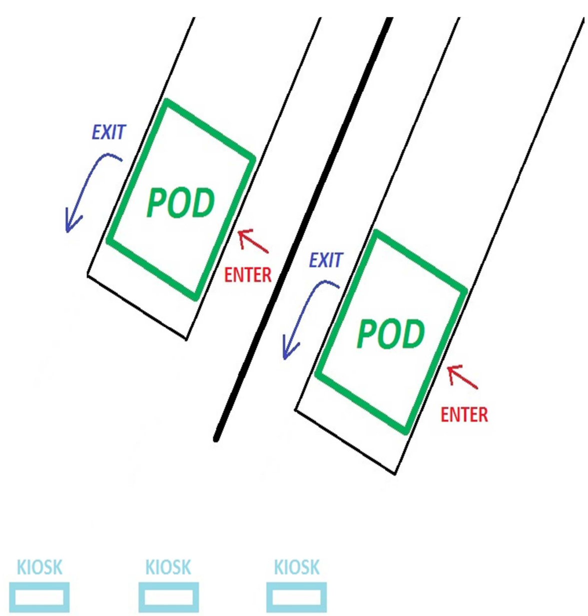


Figure 89: Layout of angle berth station

The station layout design shown in this paper take only traffic flow in to consideration. Placement of needed visuals, such as signs and instruction of how to use the system, security system, materials, and structure of the station are not considered. These will be taken into consideration next semester, when adequate resources are available.

Vehicle Storage

Vehicles will be sent to offsite stations and garages under high traffic stations when they are not in use. Vehicles sent to offsite locations can be stored, cleaned, and receive any necessary maintenance before being brought back into service. For many public transportation systems, this method is more than adequate to address vehicle storage needs.

A continuous guideway will take vehicles to and from off-site stations and garages, so that a break in the guideway will not exist. This eliminates the chance of guideway and vehicle complications, ensuring a safer system.

Solar

Solar panels are incorporated into the SuperWay system by placing them on top of the structure (Figure 90). Some of the benefits of having the solar panels on top of the structure include creating minimal visual impact. As shown in Figure 90, the solar panels can blend well into the enviroment together with the overal structure of the system. In addition, the solar panels will be high enough to reduce shading issues created by sorrounding objects such as trees and buildings, allowing for maximal solar exposure. Furthermore, the solar panels will serve as shade to the podcars passing underneath during hot days. This shading effect will in turn reduce the need for HVAC power requirements. There are some challenges however with preventing the overlift of the solar panels by wind currents. To overcome wind loads and to establish a rigid frame structure that supports the solar modules, the frame is built as a subsystem of the columns holding the guideway (

Figure **91**).

Figure 90 : Some of the benefits of having the solar panels on top of the structure include creating minimal visual impact

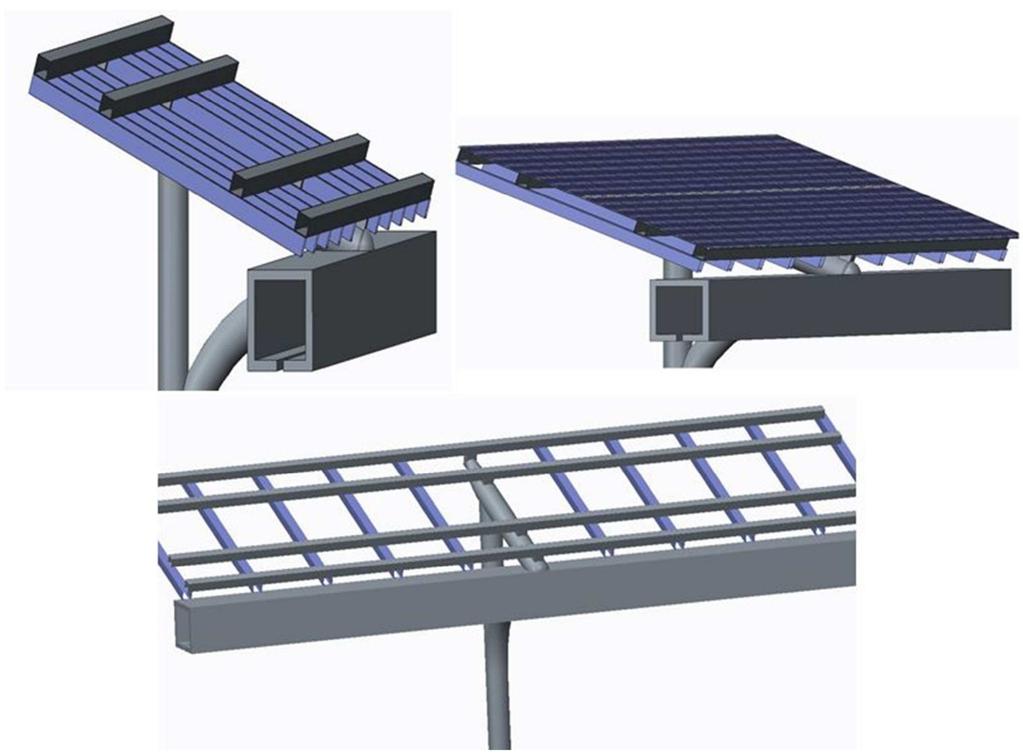


Figure 91: Solar frame structure

Figure 92 shows the top column designed at a tilt angle of 32° to maximize energy production from the PV's. The top column mounts, as also seen in Figure 92, can be designed to support the frame at whatever tilt angle is best for the residing location.

Figure 92: Top column at 32° to maximize energy

Having flat solar panels on top of the guide way does have its disadvantages. It will take longer to install and the flexibility of the panels limits the design along curved guide ways. To meet this challenge a flexible and preferably light solar cell is needed. The ALTA solar cell (as mentioned in the Solar Technology selection) satisfies this need.

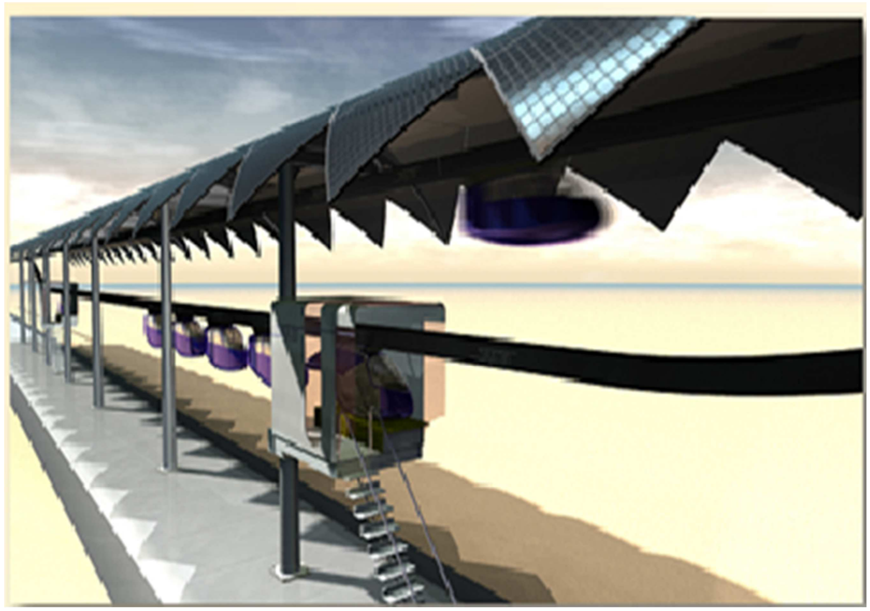


Figure 93: Curved designed solar panels have the option of being configured different ways to suit both visual appeal and energy production (skytran.com, 2012)

Based on the city of San Jose, the solar team has simulated a solar system that optimizes energy production. System Advisory Model (SAM) is a software program developed by the National Renewable Energy Laboratory (NREL) that makes performance predictions for grid connected power projects. SAM considers the type of solar panel and inverter, orientation, derates factors, location, and real weather data to predict solar energy production (for further information on SAM visit sam.nrel.gov/t). Simulations were first conducted to optimize panel tilt angle for energy production. The simulations show that a 32° tilt angle at 180° azimuth gives the maximum energy production. PV modules are known to degrade, thus to properly size the system, adequate derate factors must be assumed (for derate factors used on the simulation see Appendix A). Derate factors to consider in the performance of PV's are (but not limited to) (Mokri, 2012):

- Modules are rated under Standard Test Conditions. STC conditions are: solar cell = 25°C; solar irradiance = 1000 W/m²; and solar spectrum as filtered by passing through 1.5 thickness of atmosphere. Actual conditions need to be considered.
- Tolerance – Module output rating with a tolerance of about ± 5%.
- Temperature – Module output power reduces as module temperature increases. Temperature reduction factors vary depending on solar cell technology (crystalline is typically 89%).
- Dirt and dust – Dust build up in the dry season blocks the irradiance thus decreasing PV power performance.

- Mismatch and wiring losses: Maximum power output of the array is less than the sum of the output of the individual modules. This is a result of variations in performance from one module to the next and amounts to a 2% loss in system power.
- DC to AC conversion losses – Inverters typically have peak efficiencies of 92-96%.

For simulation purposes using SAM, a derate factor of 89% is assumed. Under these settings, with the use of a high efficient solar panel and the panels align along a straight line (east to west), simulation results that there is more than enough energy being produced to power the SuperWay. For solar panel selection criteria see Technology Selection section and for further solar panel description see

Appendix B.

Table 19: Energy Produced Under Ideal Settings

SunPower: SPR-440 NE-WHT-D Mono-c-Si	
Energy Output per Mile (kWh/mile)	3,778
Energy Available for Grid (kWh/mile)	1,334
Total Modules Required for Energy Output per Mile	1,609
Module Efficiency %	21.3

The total energy output of the system is 3,778 kWh/mile, which is 1,334 kWh/mile more than the required 2,440 kWh/mile for the SuperWay. The additional 1,334 kWh/mile can be sent to the power grid, giving the SuperWay extra financial backing.

The SuperWay solar support structure is designed to fit two rows of SunPower: SPR-440 modules, as seen in Figure 94. By having to two rows of modules, the total energy output of the system can be doubled. This will give the system an output potential of 7,556 kWh/mile.

Figure 94: Frame fits two rows of panels to double the energy output

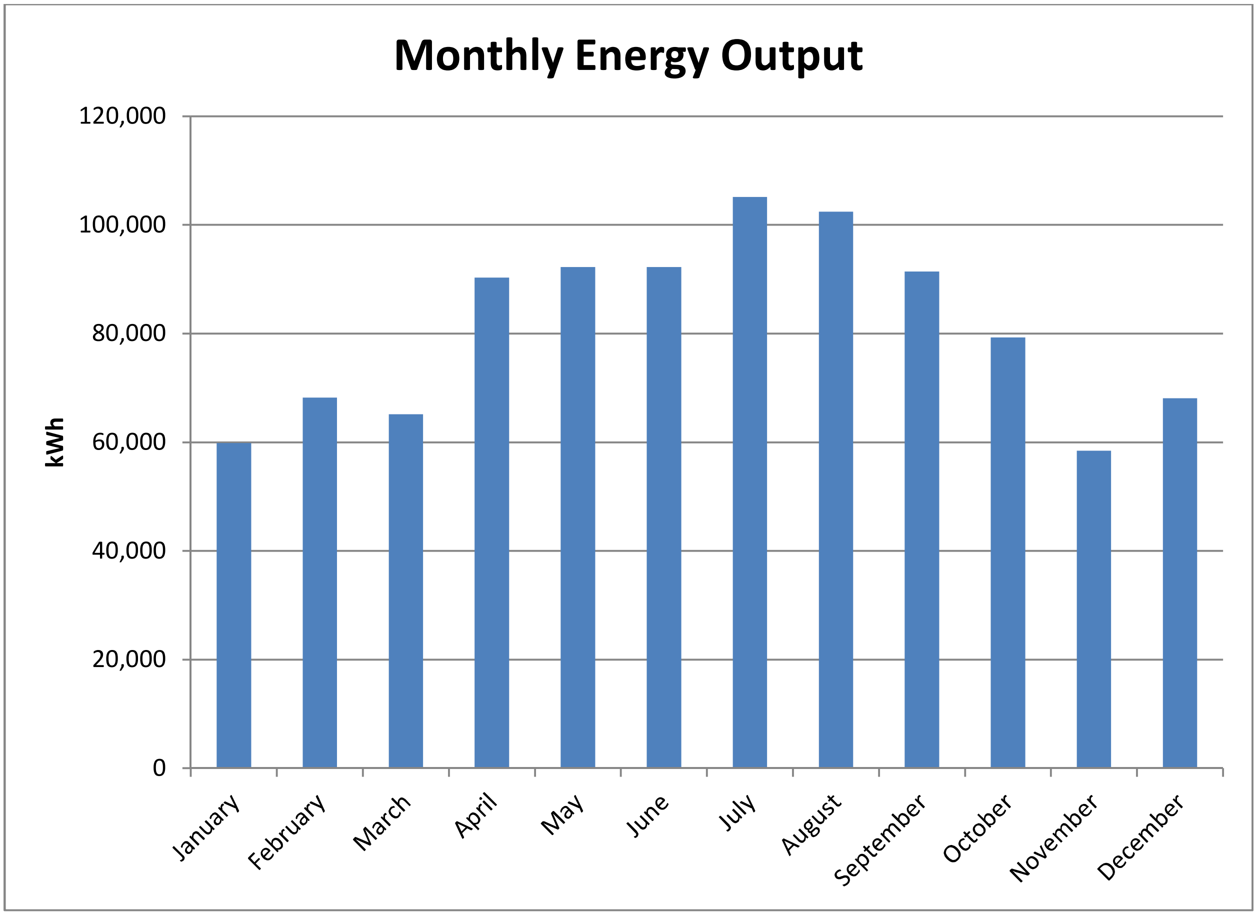


Figure 95: Monthly energy output for the Sunpower module used for simulation

Power Distribution

Power distribution is a main concern as there are many design topics that have been barely explored. Choice of inverter will depend on the power distribution of the propulsion system. It is still unclear if a DC or AC power source is needed for propulsion, so choice of inverter is far-reaching. If AC power is the main power supply to propulsion; then knowing that the SuperWay will be connected to the grid, appropriate inverters are needed. The number of inverters needs to be minimized to reduce cost. This will depend on the demand of power for a particular location or area of the SuperWay. The selection of micro-inverters versus high capacity inverters is based on trade-offs between cost and the functionality of the power distribution network (Mokri, 2012). The benefit of micro inverters is the availability of AC power on location. The disadvantage is that micro inverters are known to fatigue faster than panel inverters, due to the extra exposure of heat as they are directly connected underneath the solar panel. Each solar panel requires its own micro-inverter, this could be problematic as there would be a lot wires going through the guide way. If DC is the main power supply for propulsion, then the number of inverters will be significantly reduced. In this case, the solar panels would directly power the propulsion through a power line. Higher capacity inverters are still needed as AC power is required to connect to the grid and to use for re-distribution in high power demand areas within the SuperWay network.

Energy Storage

Energy storage will be needed for the vehicle in case of power failure. This storage system needs to be small to reduce weight of the vehicle. There are ultra-capacitors and electrochemical cells (rechargeable batteries) available in the market. The benefits of batteries are that they have a higher energy capacity and smaller weight than ultra-capacitors (lithium polymer specific energy = 18-250 Wh/kg) (Ehsani, 2010). If storage capacity is small, then the electricity from solar energy cannot be fully utilized. On the other hand, if the storage capacity is oversized then it is very rarely used in full. This means excessive, unneeded weight and added cost (Ehsani, 2012). Ultra capacitors have a specific energy of about 2.22 Wh/kg, but they provide a higher torque potential. A hybrid system of ultra-capacitors and batteries can be used to have both benefits of higher energy capacity and torque (Ehsani, 2012). To charge these batteries is trivial in which inductive power distribution is already available in the market.

Control Systems

General System Description

The control system plays a vital role in the safety of the passengers and the scalability of the platform. The control system must prioritize safety throughout the system and efficiently handle traffic. The preliminary design concept uses the system requirements discussed in the design specifications section. For reasons explained in the state-of-art, the control system was designed using a quasi-synchronous approach between multiple systems. In order to satisfy the requirements, the system was divided into smaller subsystems with specific roles. Below are the considered divisions of the system for additional specification:

Autonomous Pod Control - Safely moves the pod down the track between stations and through merge points.

Merger Controller - Coordinates merge railway intersection through monitoring and negotiation with the incoming pods.

Master Controller – Acts as the central authority for the entire system and handles alerts and routing requests from reservation system or administrator.

Reservation System - Passenger ticketing system through terminal and web accessible platforms.

Each system runs asynchronously and maintains state awareness of each other. The Pod Controller, Master Controller, and Merge Controller monitor each other's state to ensure the system is responding and fully functional.

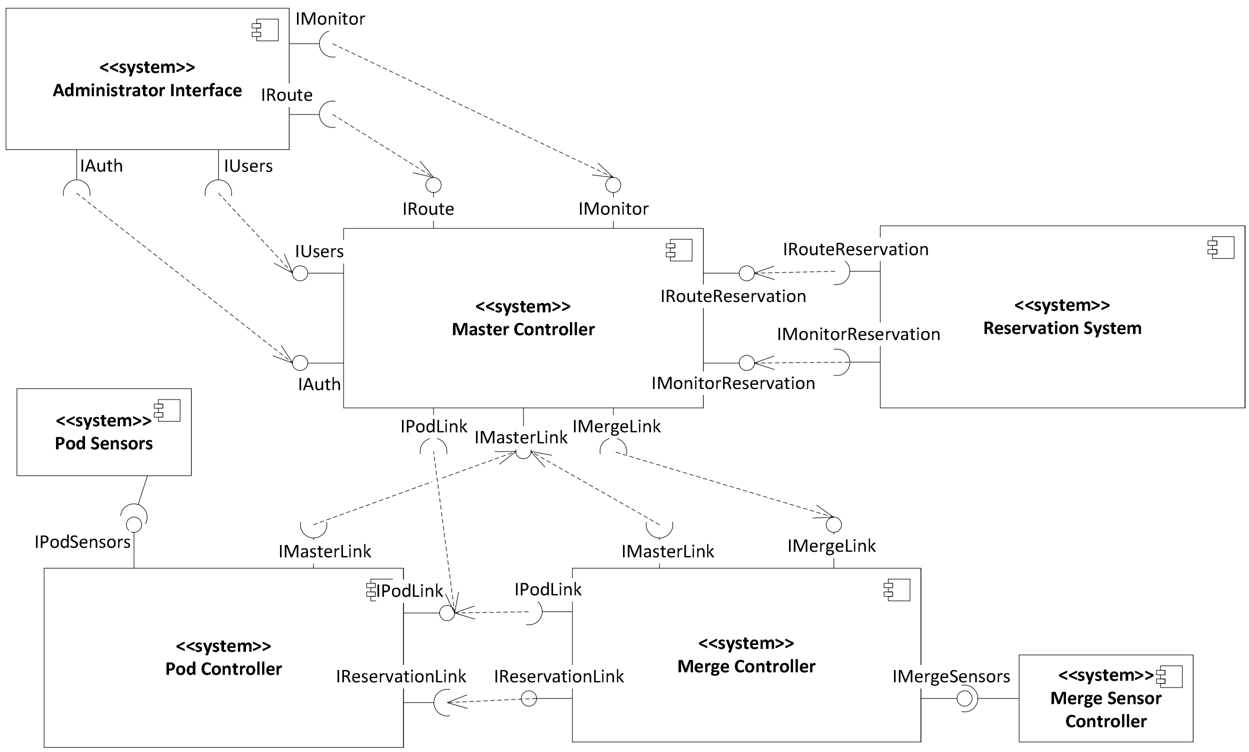


Figure 96: Control System Components and Interfaces

The above diagram outlines the systems and interfaces between the controllers in the system. The Master Controller is the central controller connected to each of the systems. The Reservation system links into the master controller with a unidirectional interface for travel times and route requests. The Pod Controller connects to the Master Controller and Merge Controller with bi-directional interfaces for communicating during merge sequences, and accepting commands from the system authority. The Merge Controller interfaces with the Pod Controller and Master Controller to manage merging procedures, and alert the Master Controller of any failures. While the Master Controller is responsible for general system monitoring and routing, the two-way communication among the controllers enable limited dependence on each other during critical alerts.

In the event of critical alerts, each controller will have the intelligence to handle the alert immediately and report the alert to the Master Controller, if available, for further resolution. For example, in the event a Pod fails in the middle of a merge, the Merge Controller should have enough intelligence to stop the incoming pods.

The following sections outline the requirements and use case scenarios of the controllers and reservation system.

Master Controller

The Master Controller is the central authority in the system that interconnects other subsystems. It is responsible for handling any system alerts, providing general routing, and managing all control subsystems. An interface is also provided for a system administrator to manage the subsystem and handle any alerts that may not be automated. The Master Controller will also implement adaptive routing routines using traffic prediction to handle traffic congestion, pathway obstructions, and peak demand requirements.

Functional Requirements

1. The Master Controller shall communicate to pod controllers to transfer empty vehicles between stations
2. The Master Controller shall manage all subsystems, except the reservation system
3. The Master Controller shall take action on system wide alerts through administrative or automated actions
4. The Master Controller shall forecast traffic to allocate vehicles to predicted heavy traffic areas beforehand.
5. The Master Controller shall have physical hardware redundancy and maintain state with other backup Master Controller
6. The Master Controller shall provide full route details to pods for entire transfer between stations
7. The Master Controller shall prioritize emergency requests
8. The Master Controller shall provide the system administrator with system wide status and routing statistics
9. The Master Controller shall provide estimated travel time data for the reservation system to implement estimated travel times
10. The Master Controller shall provide adaptive routing for congested network paths
11. The Master Controller shall monitors traffic flow throughout the network
12. The Master Controller shall monitor pod cars for possible system failures
13. The Master Controller shall schedule maintenance for predicted failures and scheduled required maintenance
14. The Master Controller shall monitor connected controller availability through an interval heartbeat, such as all pods and merger controllers
15. The Master Controller shall alert system administrator of any emergencies or maintenance requests

Master Controller Use Cases

The Master Controller interacts with many different systems and system administrators. The following use cases outline the primary functions of the Master Controller while in operation.

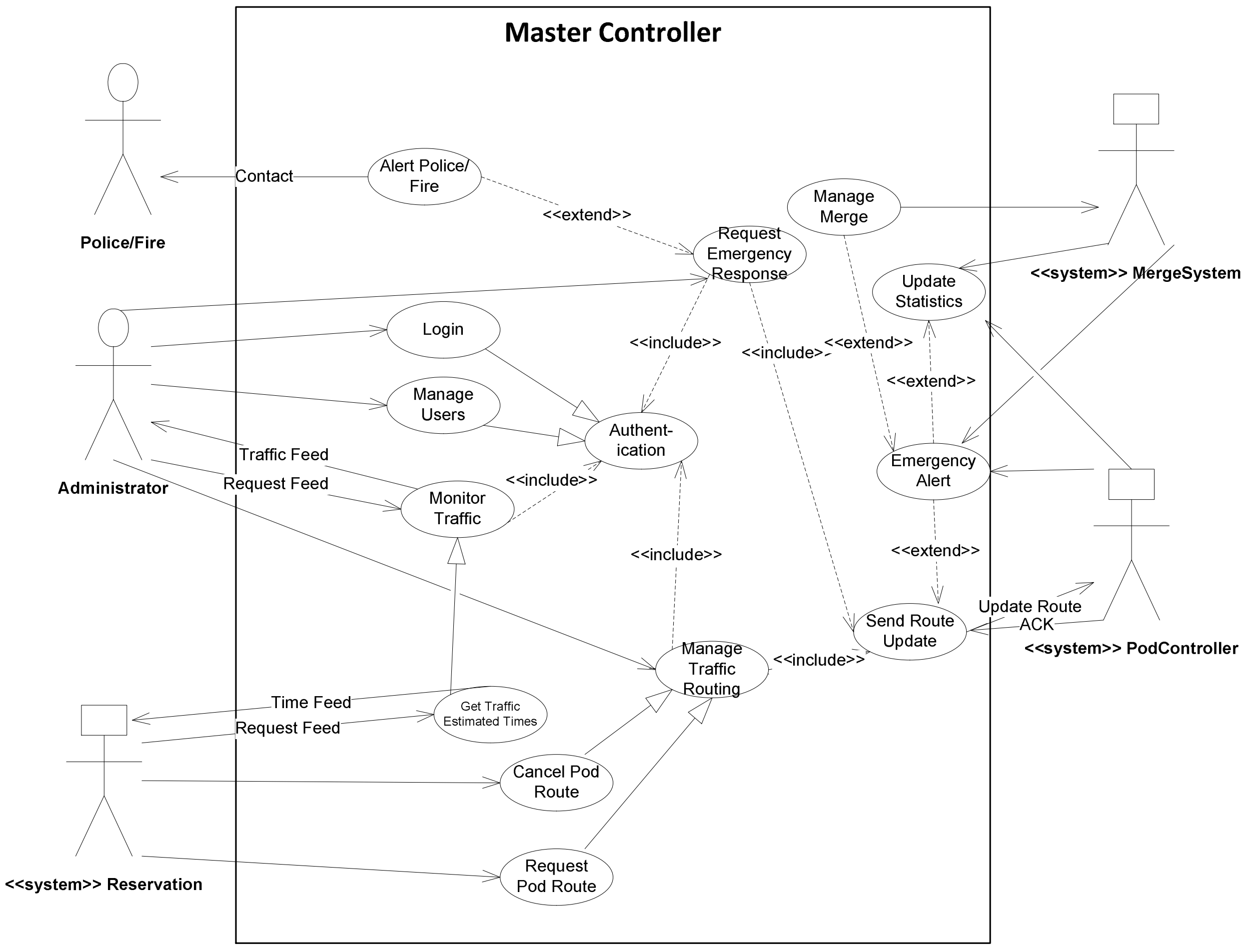


Figure 97: Master Controller Use Case Diagram

Each of the use cases above (bubbles) correlate with a use case scenario below. The use case diagram represents a visual representation of the functionality of the Master Controller. Below is a specific outline of the scenarios for each interaction.

Table 20: Master Controller Use Case Scenarios

Use	Precondition	Source	Action
Request pod routing		Reservation System	If an available pod is already at the requested station, enable boarding to pod If no pod is available at station, route an available pod from a close by station and report wait time 1. Receives route request from reservation system. 2. Route is scheduled for update to pod 3. Success or failure with estimated time is returned to reservation system
Cancel pod request	Pod route request is cancelled	Reservation System	1. Request for cancellation is sent to routing system 2. Success or failure is returned to reservation system
Get Traffic Estimate Time	Reservation system requests estimated time feed	Reservation System	Send average times between network nodes 1. The reservation system subscribes to estimated time metrics 2. Metric data will be periodically updated (10 minutes) to the subscribed system

Use	**Precondition**	**Source**	**Action**
Pod car sends statistics	Pod checks in	Autonomous System	Statistics are periodically transmitted to the master controller to update path weights and estimated time information 1. Receives pod check-in information and statistics 2. Updates router data 3. Checks off pod for check-in until next period 4. (conditional) If pod fails to check in an appropriate amount of time, issue alert
Emergency Alert	An alert from a pod or routing system has occurred	Autonomous System, Router	Autonomous System notifies the master controller of alert (i.e. emergency passenger alert, obstacle in guideway, collision). 1. Alert is sent with level of severity 2. Master controller acknowledges the alert
Receive Alert	Merge system detects a problem while merge is active	Merge System	The merge system will contact the master controller to report problem 1. Merge system sends alert message to master controller and waits for acknowledgement 2. Master controller acknowledges the alert 3. (conditional) If the alert is severe and requires merge intersection changes, the master controller will update the merge intersection settings

Use	Precondition	Source	Action
Manages Traffic routing (management includes: redirecting traffic, moving vacant pods to stations, adding priority to specific pods, etc..)		Admin	Admin sends traffic management what management needs to take place. 1. A route request with mid-level priority will be placed for the requested action. 2. The route will be scheduled until higher level routes have completed. 3. The route will be sent to addressed pods
Log in	Web application loaded	Admin	Authenticates user to access protected data. 1. Users enter username and password 2. Administrator is redirected to monitoring screen.
Manage Users	Administrator is authenticated Administrator has super-user privileges	Admin	Administrator performs system user management. Admin can add, remove, and modify users through CRUD operation. 1. The administrator selects manage users 2. Administrator can choose to CRUD users.

Use	Precondition	Source	Action
Monitors traffic	Administrator is authenticated	Admin	Master controller provides a feed of information updated with real-time traffic information redirected from the router. 1. Administrator requests real-time feed with web client. 2. A frequently updated feed is sent to the administrator to view entire system status. 3. Any Emergency alerts and traffic updates are reported to the traffic monitor system will be forwarded to the admin to take corrective action.
Request Emergency Response	Administrator is authenticated Administrator has received an emergency alert from traffic monitor	Admin	Admin gives emergency response directions to the routing system. Depending on the severity of the incident Emergency response directions can include different levels of priority. 1. Administrator requests immediate routing away from the incident 2. (optional) If an accident has occurred that involves injury, severe destruction or system wide failure, contact emergency response (police/fire) 3. Administrator sends update response to send update route

Use	Precondition	Source	Action
Send Update Route	Route update received from Administrator or Reservation System	Master Controller	Updates pod route information to travel for the particular path. Several sources update pod route information and require different priority levels. From top to lowest priority, emergency response (administrator), manage traffic routing (administrator), and lastly the reservation system. All route updates can be to a specific pod or broadcasted to multiple pods. 1. All received updates are prioritized and executed in order of prioritization. 2. Routes are checked against previous request for conflicting instructions. 3. The route is sent to the addressed pods 4. Addressed pods reply back with acknowledgement 5. Update acknowledgement checked 6. (conditional) If acknowledgement is not received, go to step 3 up to two times 7. (conditional) If send update failed, issue alert.

Use	Precondition	Source	Action
Manage Merge	Master controller need to update intersection settings The master controller if functioning	Master controller	The merge system will have a variety of settings, such as intersection speed, and merge proximity that the master controller will need access to. 1. The master controller sends the update data to the merge system. 2. The merge system will reply with an acknowledgement that the data was successfully updated. 3. (conditional) if the data was not updated, it will reply with the error encountered.

Master Controller Components

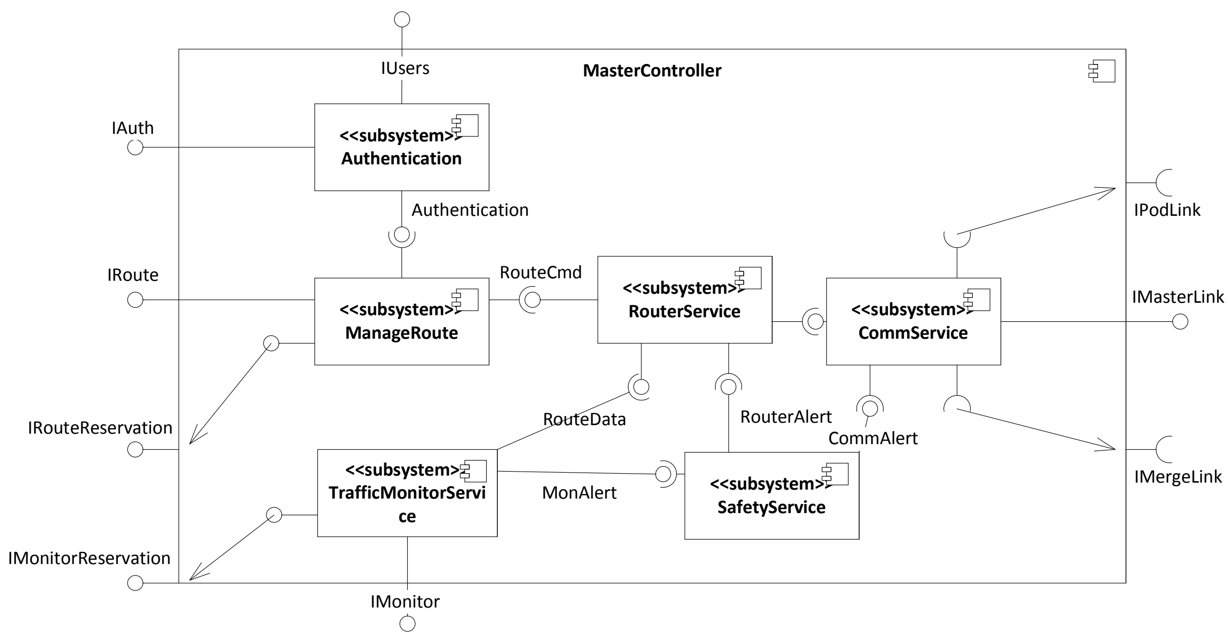


Figure 98: Master Controller Components

The Master Controller is divided into several asynchronous subsystems. Each component is responsible for a particular set of use cases from the above table.

Authentication - Provides security for the interfaces used with external systems from the primary control system. All user management and authentication protocols will be handled by this subsystem.

ManageRoute - Provides an interface for the reservation system and system administrator to manage pod routing and merge controllers. The Reservation system can only request and cancel pod routes from the IRouteReservation, while the system administrator has full access through the IRoute interface.

RouterService - Provides the backend logic for the adaptive routing algorithms and tracks the status of pod and merge controllers throughout the system. It also provides real-time system data to the TrafficMonitorService for monitoring.

TrafficMonitorService - Provides the interface for the reservation system and system administrator to monitor system traffic and pull estimated travel times.

SafetyService - Monitors the system for alerts from Pod and Merge controllers and RouterServices. Any alerts may be handled through automated responses or sent to TrafficMonitorService to be transferred to a system administrator for further handling.

CommService - Provides a network interface between the merge and pod controllers to transfer data throughout the control system.

An Example Routing Request Sequence

When a ticket is purchased in the reservation system, a routing request is sent to the Master Controller. The Master Controller sends the routing information to an available pod controller and the pod follows the route turn-by-turn to the destination.

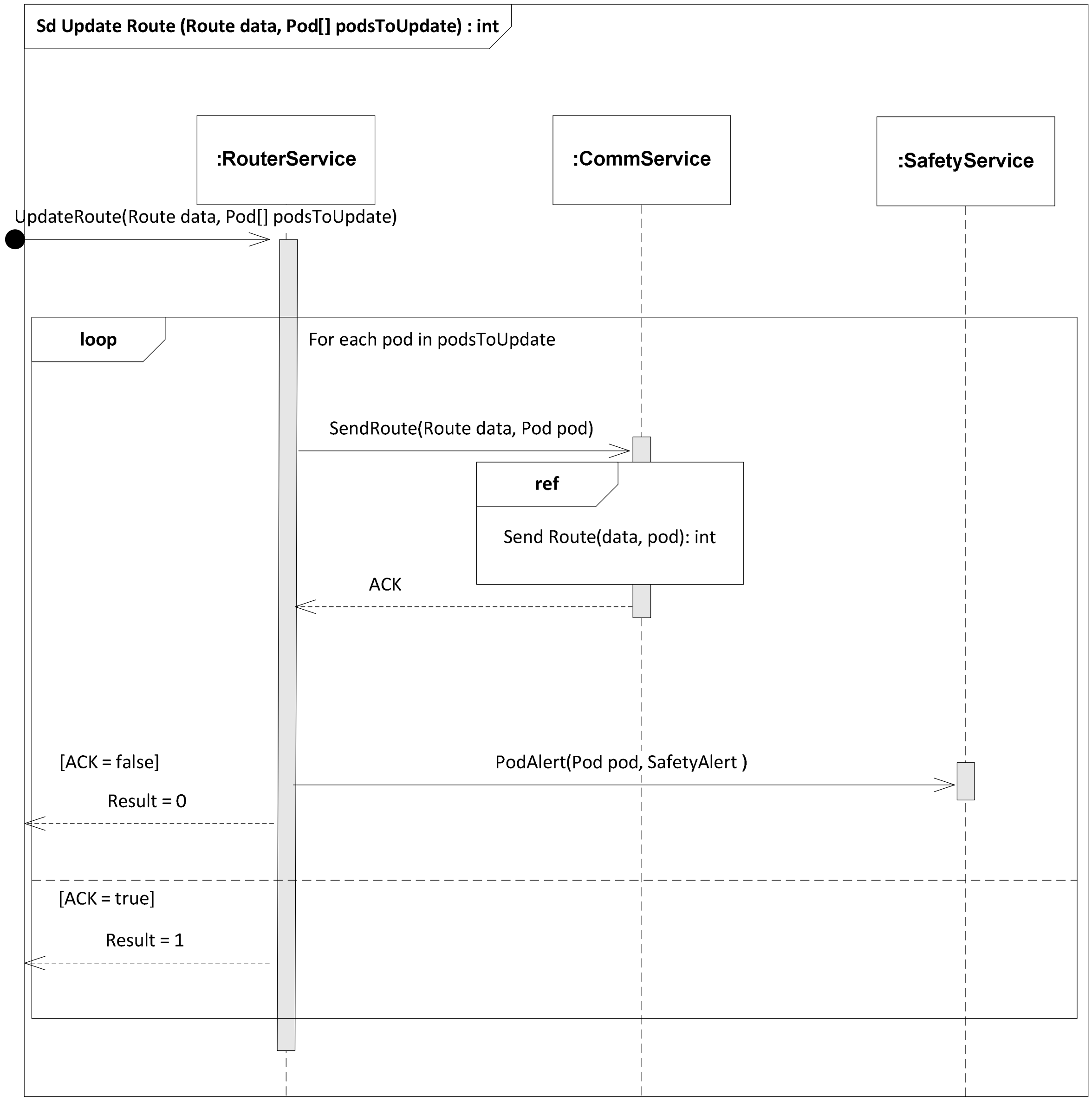


Figure 99: Master Controller Update Route Sequence

The sequence above outlines the update request from the ManageRoute component. If a route is purchased or a system administrator orders a pod to move, the route data is sent to the CommService to be passed on to an available pod. If the route request fails, an alert is issued.

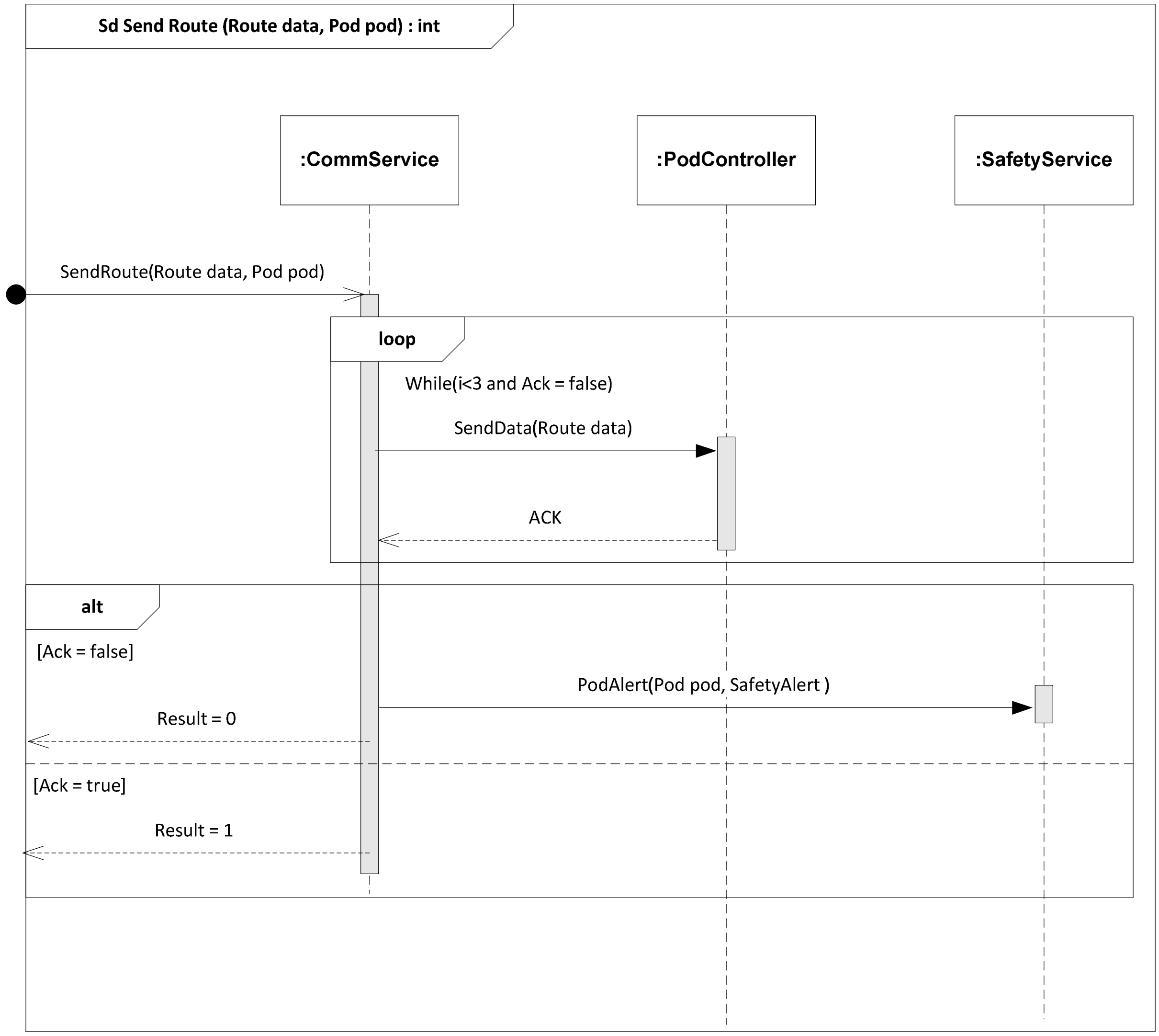


Figure 100: Master Controller Send Route Sequence

The above sequence is an expansion of the first Update Route sequence. During the Update Route sequence, the communication is handled through the CommService to transfer the data to the addressed pods. The data is sent to the pod directly through a communication medium and the CommService waits for an acknowledgement. After three sends, the send route fails and an alert is issued.

Merge Controller

Functional Requirements

1. The Merge System must be aware of the pods approaching the intersection
2. The Merge System shall alert the Master controller when a problem is detected
3. The Merge System shall periodically tell the Master Controller it is available

4. The Merge System shall be managed by the Master controller
5. The Merge System shall have redundancy for hardware and sensors
6. The Merge System must be able to communicate directly with the pods

Merge Controller Use Cases

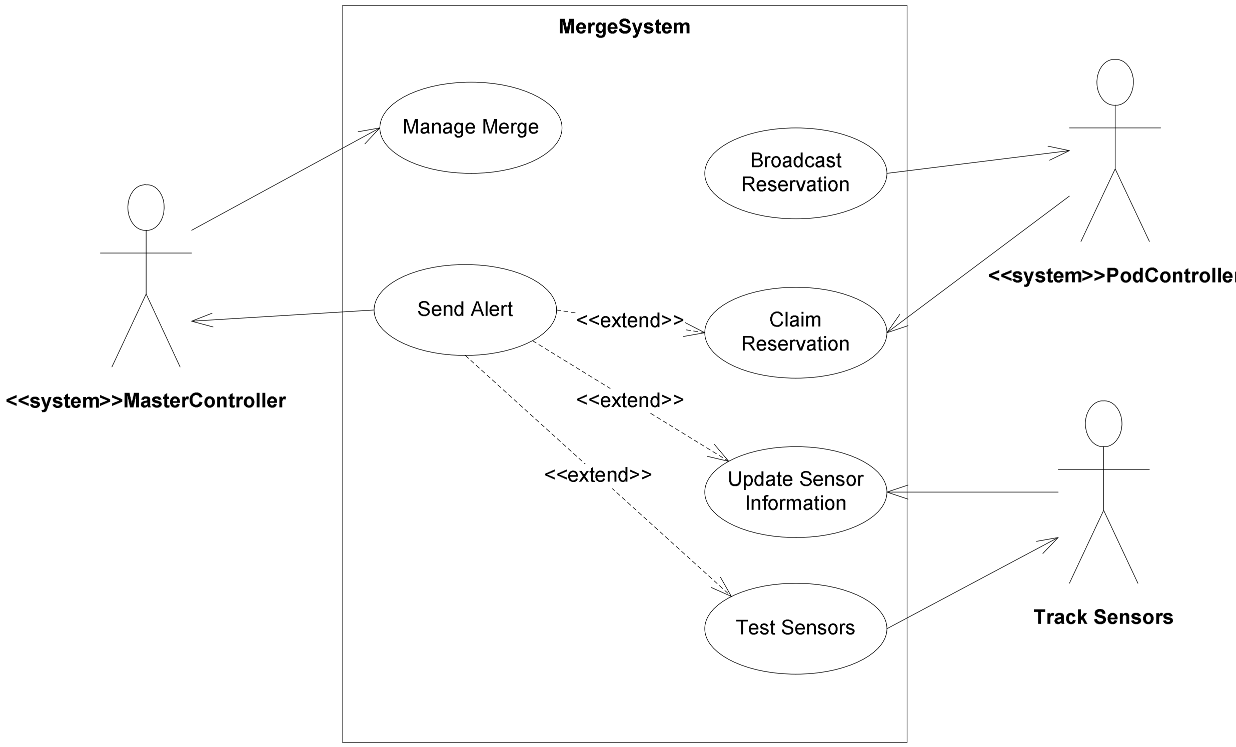


Figure 101: Merge Controller Use Case Diagram

The above diagram outlines the external interactions to the Merge Controller. For every use case (bubble) in the diagram, a correlating scenario exists in the table below.

Table 21: Merge Controller Use Case Scenarios

Use	Precondition	Source	Action
Send Alert	Merge system detects a problem while merge is active	Merge System	The merge system will contact the master controller to report problem 1. Merge system sends alert message to master controller and waits for acknowledgement 2. Master controller acknowledges the alert

Use	Precondition	Source	Action
Manage Merge	Master controller need to update intersection settings The master controller if functioning	Master controller	The merge system will have a variety of settings, such as intersection speed, and merge proximity that the master controller will need access to. 1. The master controller sends the update data to the merge system. 2. The merge system will reply with an acknowledgement that the data was successfully updated. 3. (conditional) if the data was not updated, it will reply with the error encountered.
Test Sensors		Merge System	The merge system will intermittently check sensors to ensure responsiveness and accuracy. 1. Merge system sends test command to sensor controllers 2. Sensor controllers respond with test data
Request Reservation	A reservation has been broadcasted and received by a pod	Pod Controller	Pod controller attempts to claim a reservation broadcasted by the merge system for a position in merge sequence. 1. Pod controller send pod address information and distance from merge 2. (conditional) If the pods distance is closest to intersection, merge system will approve the reservation for the pod and wait for acknowledgement. 3. (conditional) If Pod controller does not respond with Acknowledgement, stop incoming pods and send alert to master controller for further instructions

Use	Precondition	Source	Action
Update Sensor Information	Sensor controllers have gathered updated information	Merge system Sensors	The sensors will frequently update the merge system with detected pod positions and other important information for merging the pods together. 1. Sensors send merge system updated data 2. (conditional) If sensors fail to update periodically, stop merge traffic and alert master controller
Gather Merge Statistics	Master Controller has requested merge status	Master Controller	The Master Controller checks the status of the merged intersection and gathers statistics. 1. Master controller requests statistics 2. Merge system responds with updated statistics 3. (conditional) If merge is not available, issue alert.

Merge Controller Components

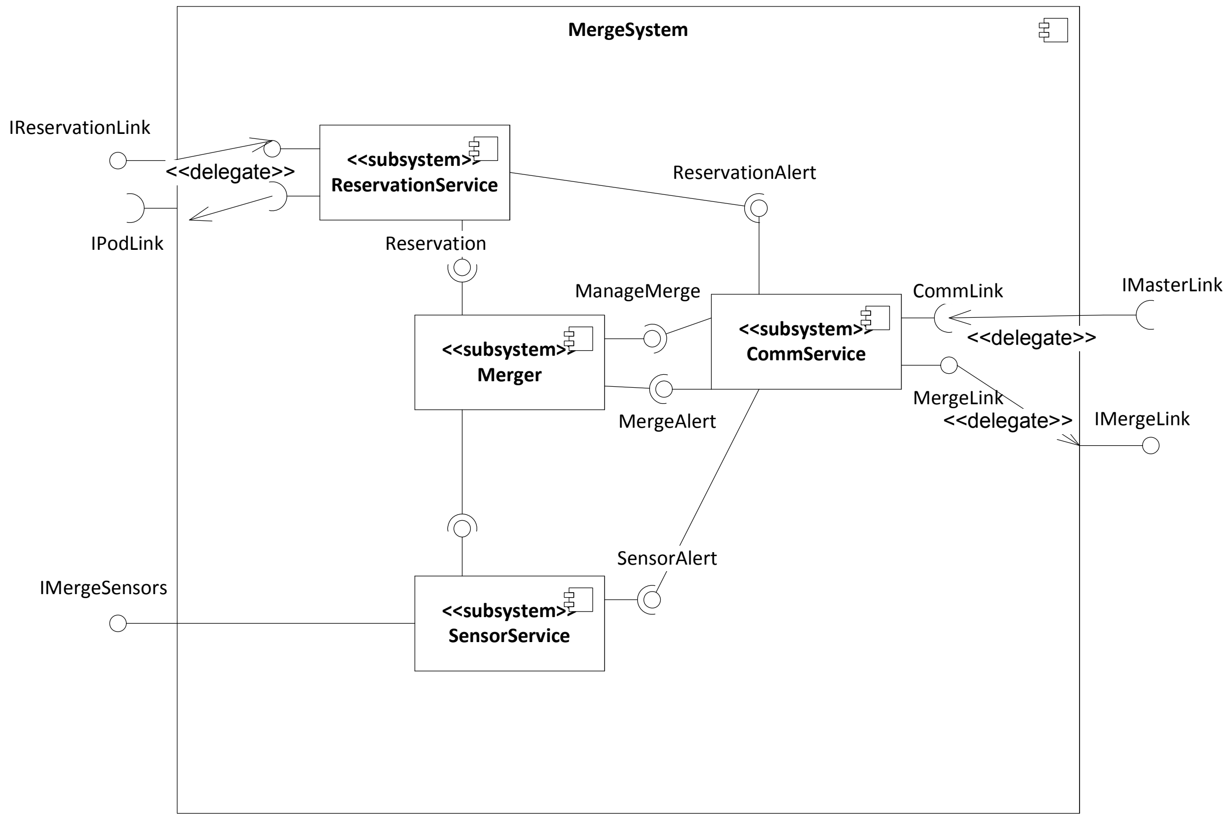


Figure 102: Merge Controller Components

The Merge Controller is divided in to four subsystems. Each subsystem is responsible for a set of use case scenarios.

ReservationService – Provides communication with merging pods during the merging sequence.

Merger – The Merger is responsible for reading the SensorService information, tracking reservations, keeping merge statistics and predicting possible failed merges. In the case of an alert, the Merger may stop all incoming traffic to the merge intersection.

CommService – Provides an interface to communicate to Master Controller.

SensorService – Maintains sensor data which detects incoming pods and position relative to merge point. It also detects failures in track sensors.

A Typical Merge Sequence

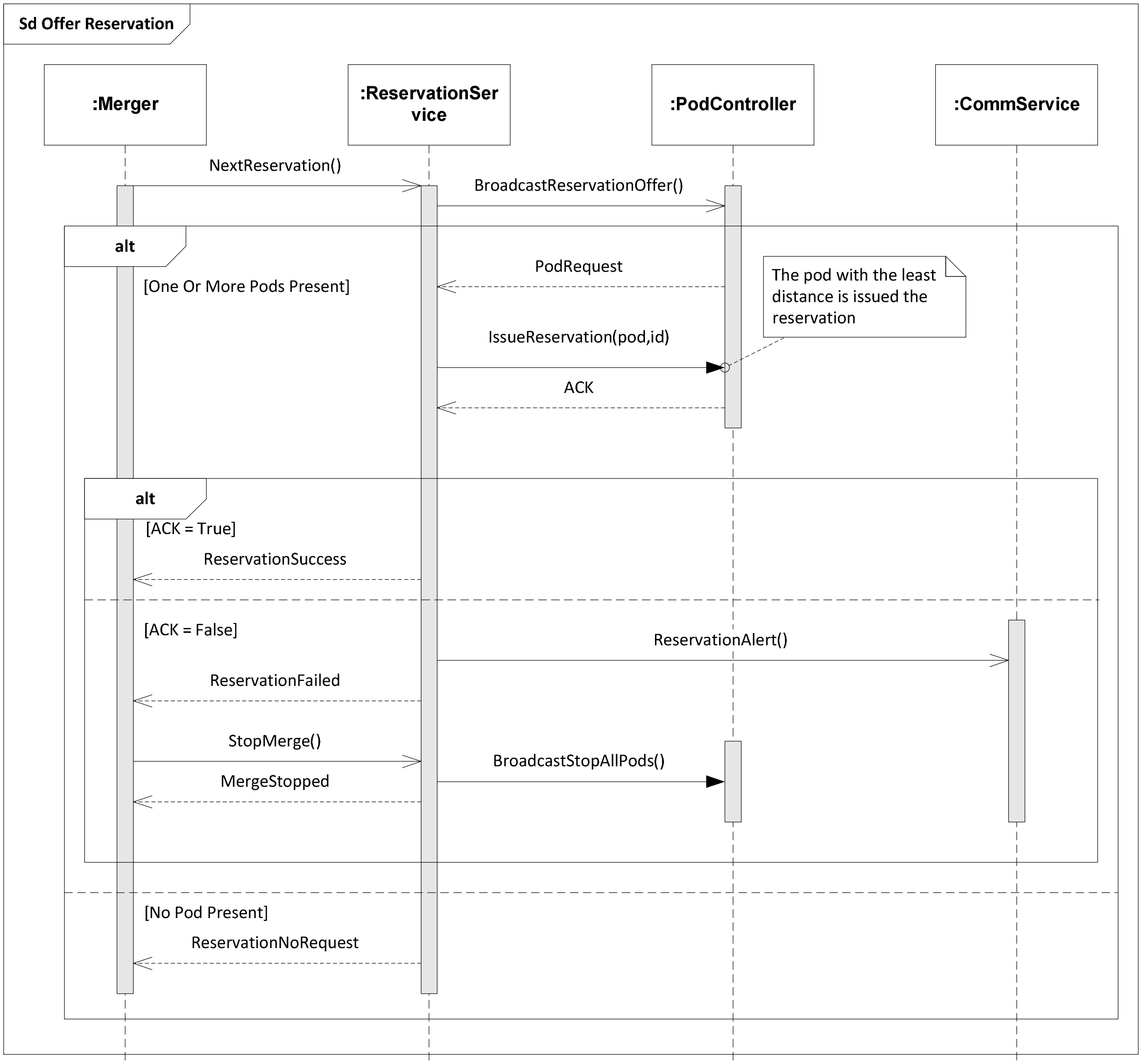


Figure 103: Merge Control Offer Reservation

The Merge Controller uses moving points to represent positions the pods can follow to safely make it through the merge intersection. To hand off points to the pods, a reservation system is used for the pods to claim a position to move through the merge intersection. The sequence diagram above shows the negotiation between the merge controller and the pod controller for the reservation being offered.

From the above diagram, the Merge Controller broadcasts an offer to all of the local pods approaching the intersection. The pod controller with least distance from the intersection is given the next attainable reservation point. If a pod fails to acknowledge an issued reservation in an appropriate amount of time, the merge is stopped and the Master Controller is alerted (if available).

Autonomous Pod Controller

The Autonomous Pod Controller is a satellite system that directly and constantly communicates with the Master Controller. It performs functional and non-functional requirements that are required on the pod such as user alerts, hardware malfunctioning detection, provide user interface, driving motors, etc. Note: that Autonomous Pod Controllers do not directly communicate with each other. Each pod is designed to operate without the awareness of other pod controllers. However, it still has the capability to provide safety to users, talk to other systems, and perform merging.

Preliminary Requirements

1. The Autonomous Pod Controller (APC) shall establish communicate to master controller
2. The Autonomous Pod Controller shall have an emergency response routine to handle the following
    a. Critical emergency alert + pod is immobile
    b. Non-critical emergency alert + pod is immobile
    c. Non-critical emergency alert + pod is mobile
3. The Autonomous Pod Controller shall be able to receive routing information
4. The Autonomous Pod Controller shall be able to control its motors
5. The Autonomous Pod Controller shall be able to drive from origin to destination with routing information
6. The Autonomous Pod Controller shall be able to read sensor information of surrounding area
7. The Autonomous Pod Controller shall keep pod on guideway
8. The Autonomous Pod Controller shall check for hardware failure
9. The Autonomous Pod Controller shall check for guideway blockage
10. The Autonomous Pod Controller shall update its statistics to Master Controller constantly
11. The Autonomous Pod Controller shall provide safety to users inside in the pod
12. The Autonomous Pod Controller shall be able to perform parking at a station
13. The Autonomous Pod Controller shall be communicating to Merging System
14. The Autonomous Pod Controller shall receive merging reservation information from merge system
15. The Autonomous Pod Controller shall perform merging at intersection
16. The Autonomous Pod Controller shall provide communication between passenger and Master Controller

Pod Controller Use Cases

The following table shows all interaction cases between the pod controller and other subsystems. UML Use Case diagram is used to illustrate the table.

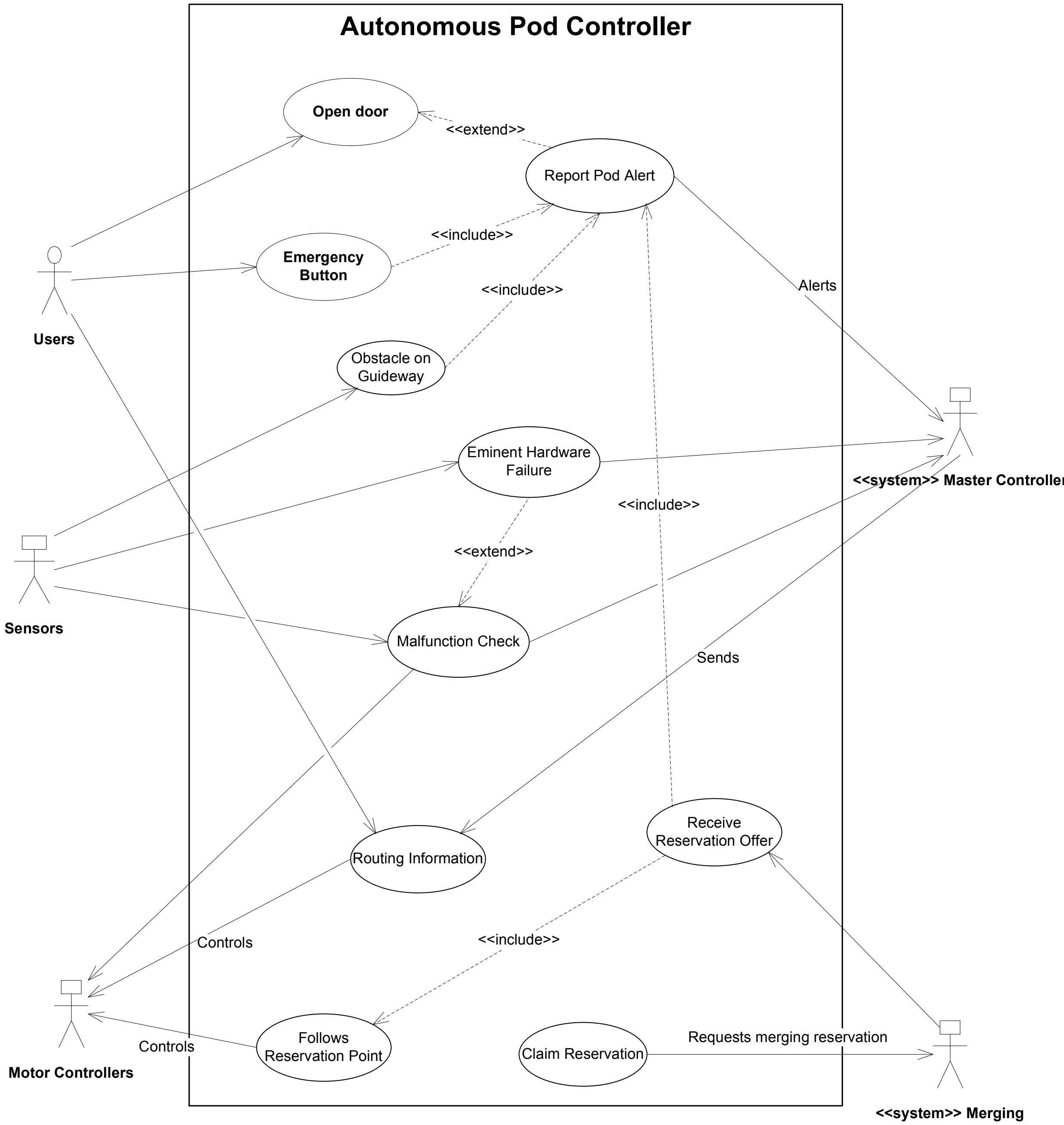


Figure 104: Pod Controller Use Case Diagram

The above diagram outlines the external interactions to the Pod Controller. For every use case (bubble) in the diagram, a correlating scenario exists in the table below.

Table 22: Pod Controller Use Case Scenarios

Use	Precondition	Source	Action
Detection of hardware failure		Pod Sensors	The pod system detects hardware failure for sensors and other parts (i.e. Motors, power, door controllers) An alert is sent to master controller (condition) If critical and immobile, stop and wait (condition) If non-critical and mobile go to nearest station If warning and mobile (i.e. low tire pressure), proceed to destination and wait for maintenance.
Merging	Merging System is functional, communication is established, pod acknowledges merging system	Pod Controller, Merging	Pod comes near an intersection Pod will "claim reservation" from Merging controller (conditional) If Merging controller sent back reservation offer, pod will proceed to intersection by following reservation point (conditional) If merging controller did not provide reservation, pod will stops and sends alert to master controller
Sensors Malfunction		Pod Sensors	Initiates emergency alerts
Obstacle encountered on guideway		Pod Sensors	Initiates emergency alerts
Emergency button is pressed		User	Establish communication with Master controller + initiate emergency alerts
Routing information is received		Master Controller	Master Controller has sent routing information => sends route to Motor Controller
Report Pod Alert	An emergency has occurred or detected in the pod	Passenger, Sensors	The pod has an alert that needs to be handled by the master controller. The alert is sent to the master controller. The master controller acknowledges

Pod Controller Components

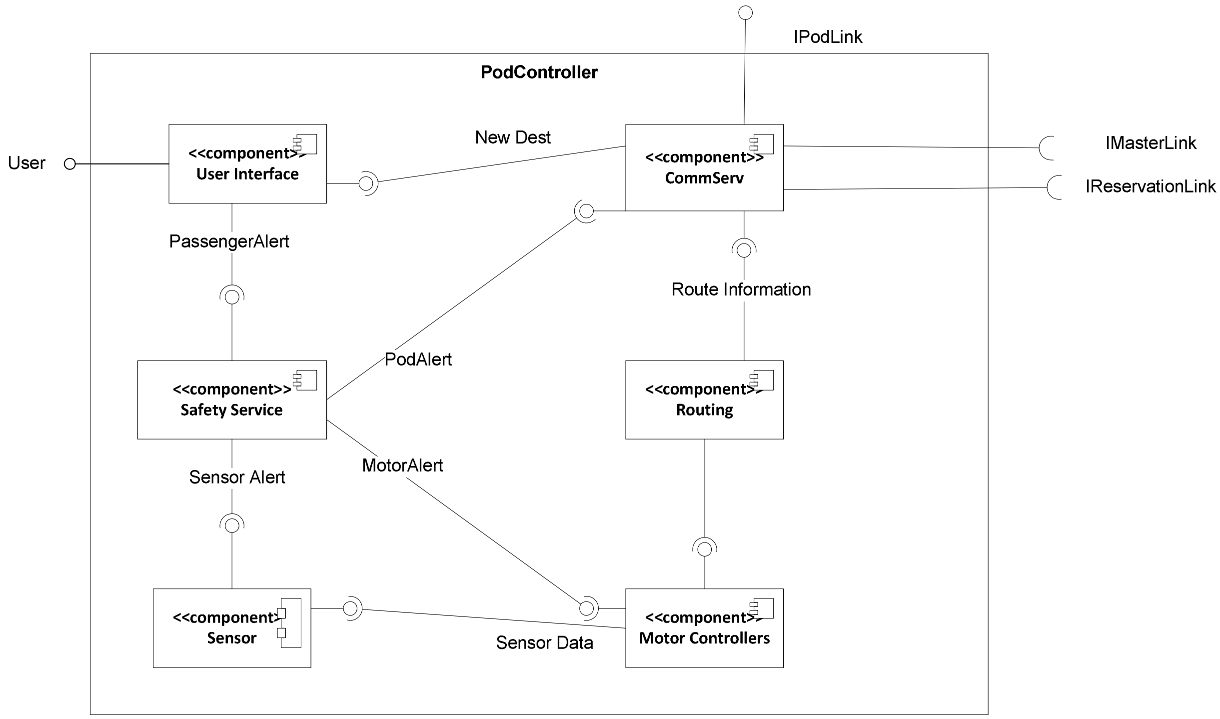


Figure 105: Pod Controller Component Diagram

In the diagram above, all components of the Autonomous Pod Controller are shown. This component diagram shows interfaces that are provided between components of the system. For example, the User Interface component provides an interface for the Safety Service component. This interface allows users, when inside the pod, to report an emergency to the Pod Safety Service. Safety Service component in turn will report the emergency alert to Master Controller through Communicating Service component. There are two links coming out of Pod Controllers, IMasterLink and IReservationLink. These two links are responsible for showing the connection between Pod and Master Controller (IMasterLink), Pod and Merging (IReservationLink) via interfaces.

Pod Controller Sequence Diagrams

The two diagrams below demonstrate the interaction between components of the Autonomous Pod Controller. In this diagram, the interactions are presented in order of occurrence (vertically)

Merging Sequence

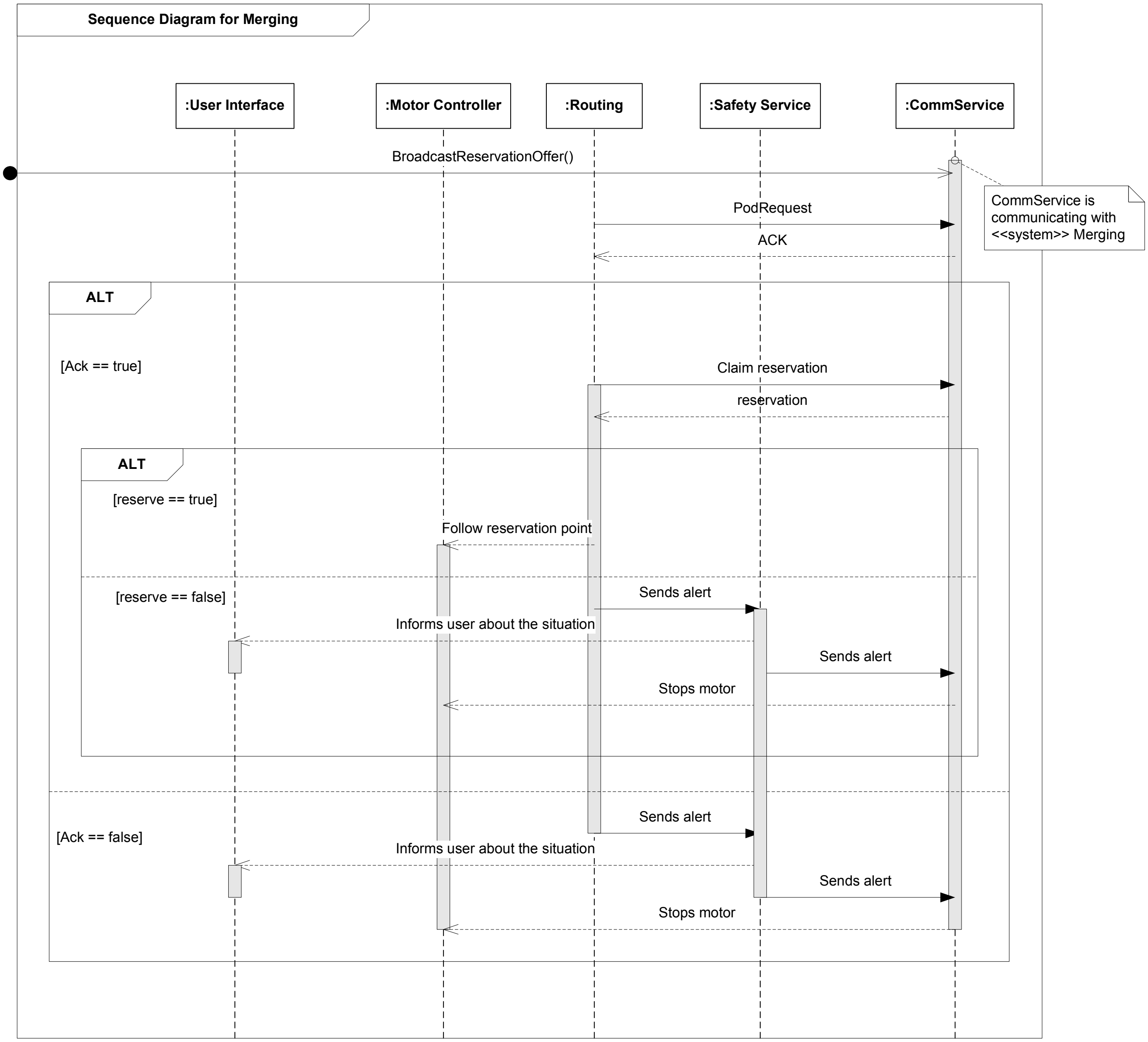


Figure 106: Pod Controller Merge Sequence

Autonomous Pod Controller is designed to be expecting a merging broadcast constantly. When the pod approaches an intersection, it will receive a broadcast of reservation offer from the Merging system. Autonomous Pod Controller now will perform a hand-shaking communication with the Merging System. First, it will claim the reservation offer. Merging System will now send information about the time that the pod will have to be at the intersection. The diagram also shows the emergency response routine take place when there is error in receiving merging broadcast. Users will also be informed of any emergency happen while an alert is sent to Master Controller.

Hardware Failure Detection Sequence

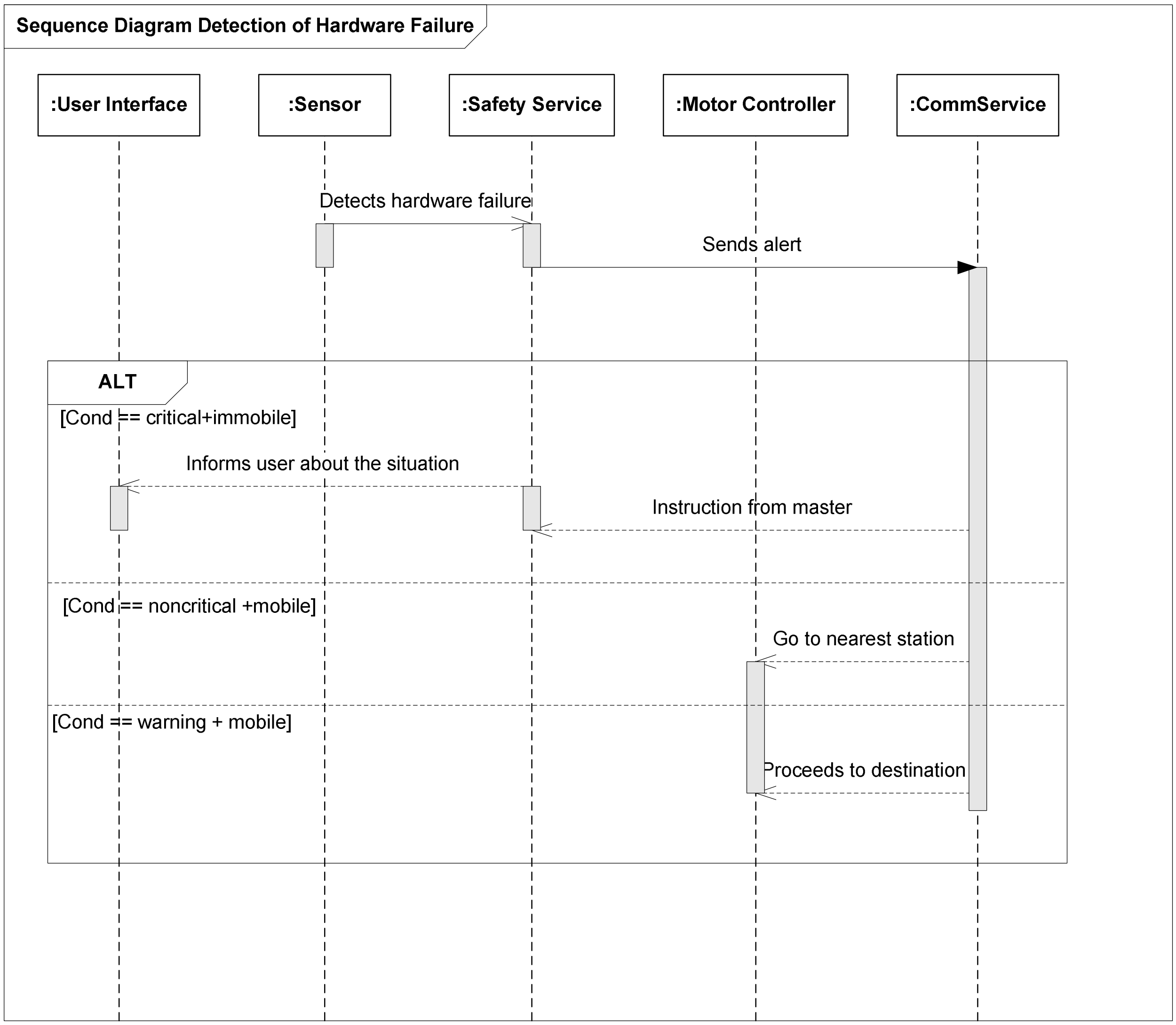


Figure 107: Pod Controller Hardware Failure Sequence

For this Hardware Failure Detection Sequence diagram, three cases of hardware failure are illustrated. The sequence starts with pod sensors detect a hardware failure. The message automatically is sent to Safety Service. Safety Service now will alerts Master Controller about this failure via Communication Service. If the failure was critical and the pod is immobile, pod will stop and wait for instructions. If failure is noncritical and the pod is mobile, it will go to the nearest station and wait for further instruction. The last case is if the failure is just a warning, the pod will keep moving to its destination. In all three cases, users are informed of the situation.

Reservation System

Preliminary Requirements

1. The Reservation system shall keep track of all reservations made by customers
2. The Reservation system shall provide Master Controller with Pod Request Details
3. The Reservation system shall alert Master Controller to reserve pods only when Master Controller is notified that the payment for the trip was successful.
4. The Reservation system shall provide E-Ticket system with trip, customer, and payment details so E-Ticket system encrypts it in the bar code.
5. The Reservation system shall only confirm reservation to the customer when Payment Processor confirms credit card is valid.
6. The Reservation System may be accessed through a phone application or an internet browser.
7. The Reservation System must be capable of knowing estimated travel times using real-time traffic information from Master Controller.

Reservation System Use Cases

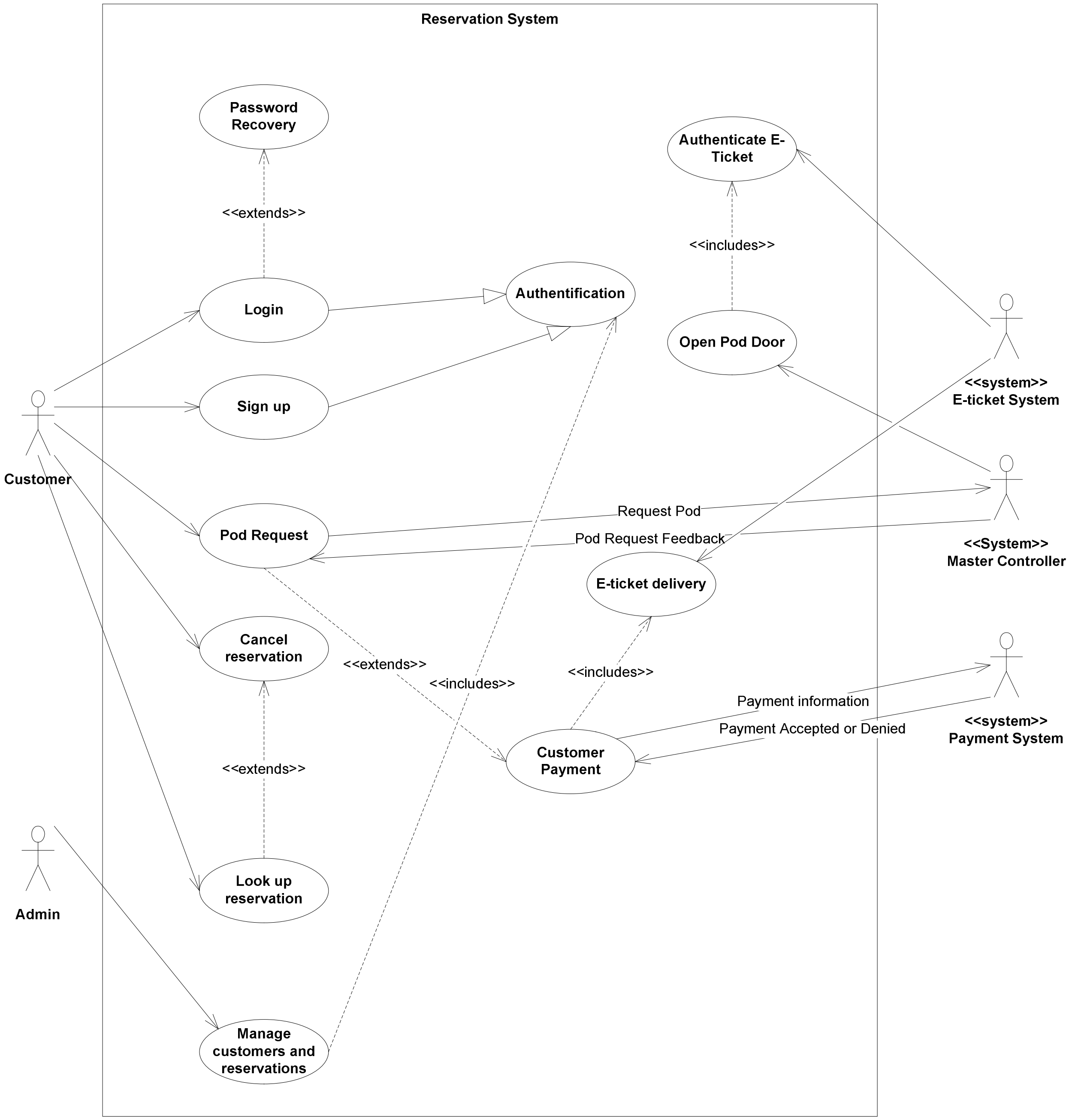


Figure 108: Reservation System Use Case Diagram

The above diagram outlines the external interactions to the Reservation System. For every use case (bubble) in the diagram, a correlating scenario exists in the table below.

Table 23: Reservation System Use Scenarios

Use	Pre-Condition	Source	Action
Sign up	Customer never signed up before	Customer	Customer creates account
Log in	Customer already signed up	Customer	Customer gets authenticated. If failure, customer redirected to password recovery screen
Password Recovery	Log in failed	Customer	Customer asked security questions Password reset
Request Pod at certain time	Logged in	Customer	Request is sent to Master Controller Success or other alternatives to pick from sent back to customer
Customer payment	Pod Request successful	Payment System	Payment system charges customer through credit card information Payment success or failure notification sent back to customer
E-ticket sent to customer	Payment Successful	E-Ticket System	Customer receives E-ticket with bar code and station number on it.
E-ticket authenticated at the door	Pod is at the station.	E-Ticket System	Door opens if ticket authenticated properly by the ticketing system.
Pod car Door is opened		Master Controller	Master Controller requests pod door to open
Cancel Reservation	Reservation is on the system already	Customer	Reservation cancelled by customer
Look up reservations	Logged in	Customer	Feedback of all reservations made by customer
Manage customers and reservations	Logged in	Admin	Admin helps with password recovery (if authentication fails) and database maintenance.

Reservation System Components

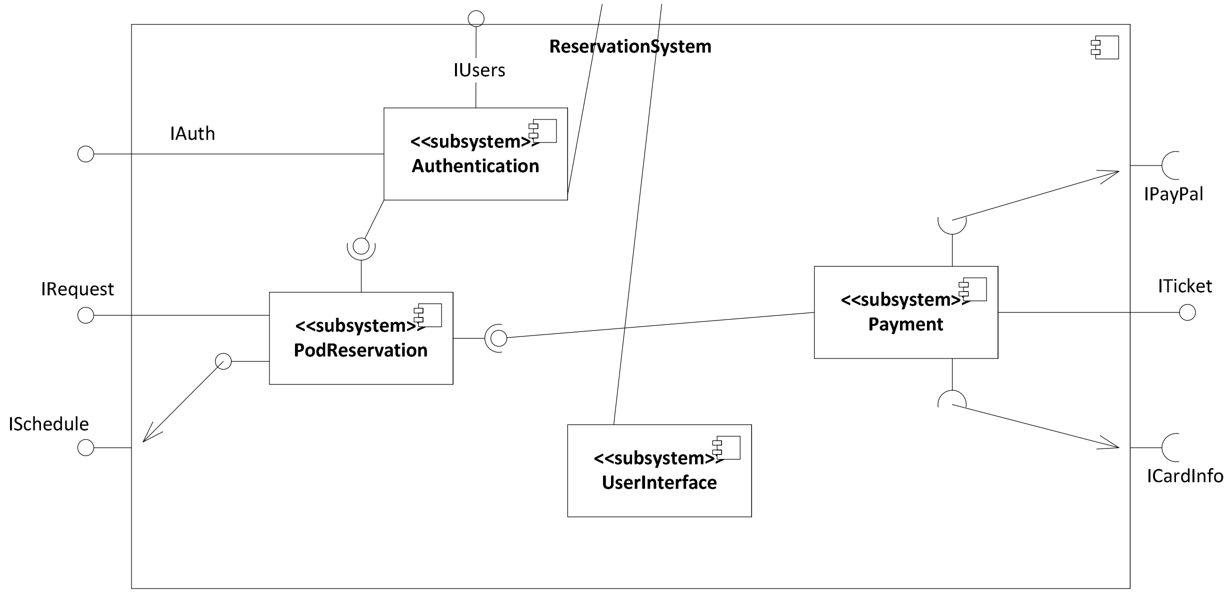


Figure 109: Reservation System Components

The Reservation System is divided into several components each responsible for a particular aspect of the reservation system.

Authentication – Customer and Admin login will be handled by this subsystem in a secure manner to avoid fraud and system errors.

UserInterface - Provides an interface for the customer to manage, create, and delete reservations and for the admin to manage customers and transactions. UserInterface is only accessed after authentification. Customer has restricted access and Admin has full privileges.

PodReservation - Provides the backend logic linked to the Master Controller to figure out which Pod to send to the customer depending on the requested time.

Payment - Provides the customer with a web browser side interface for payment. Card information is inputted. Reservation is only confirmed when Payment is confirmed.

Reservation System Sequence Diagrams

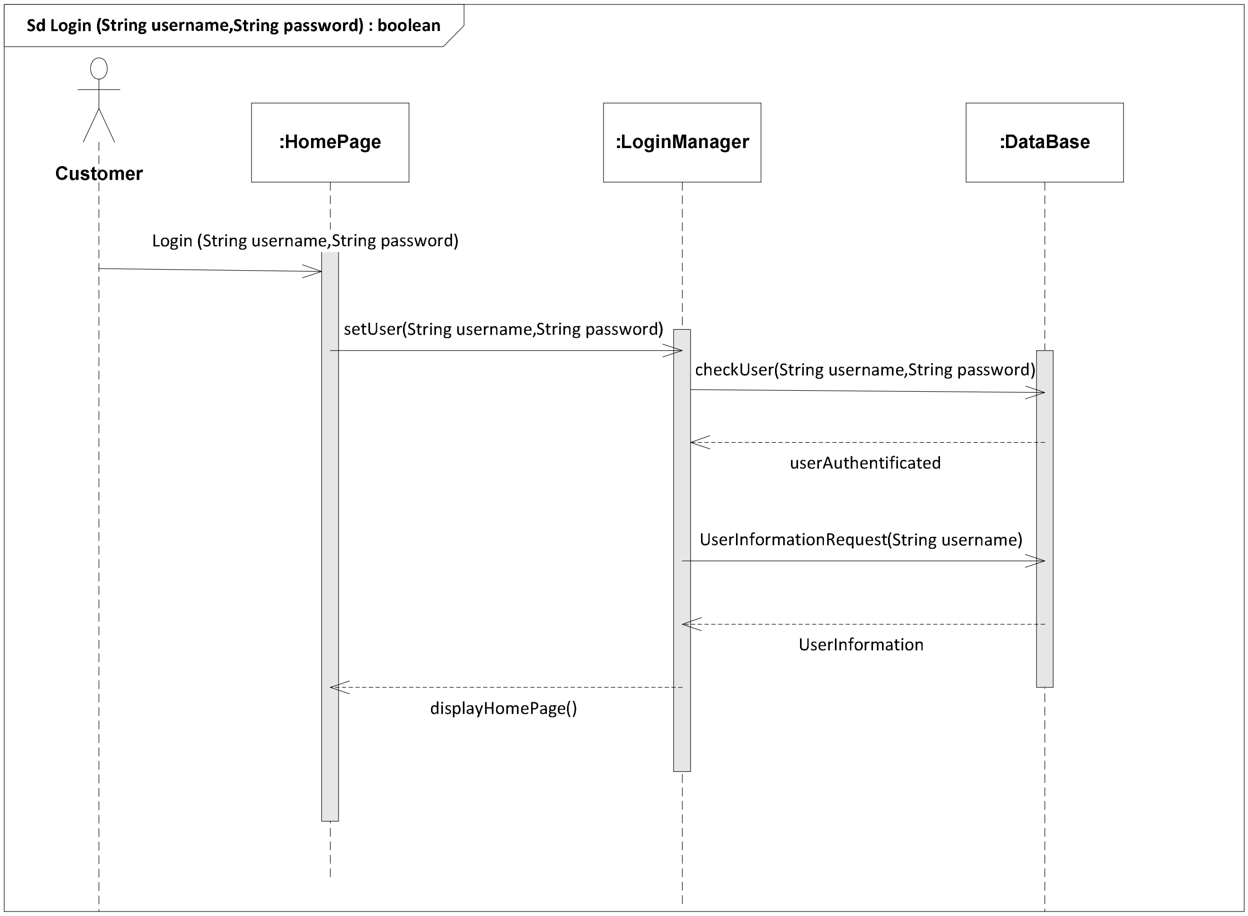


Figure 110: Reservation System Login Sequence

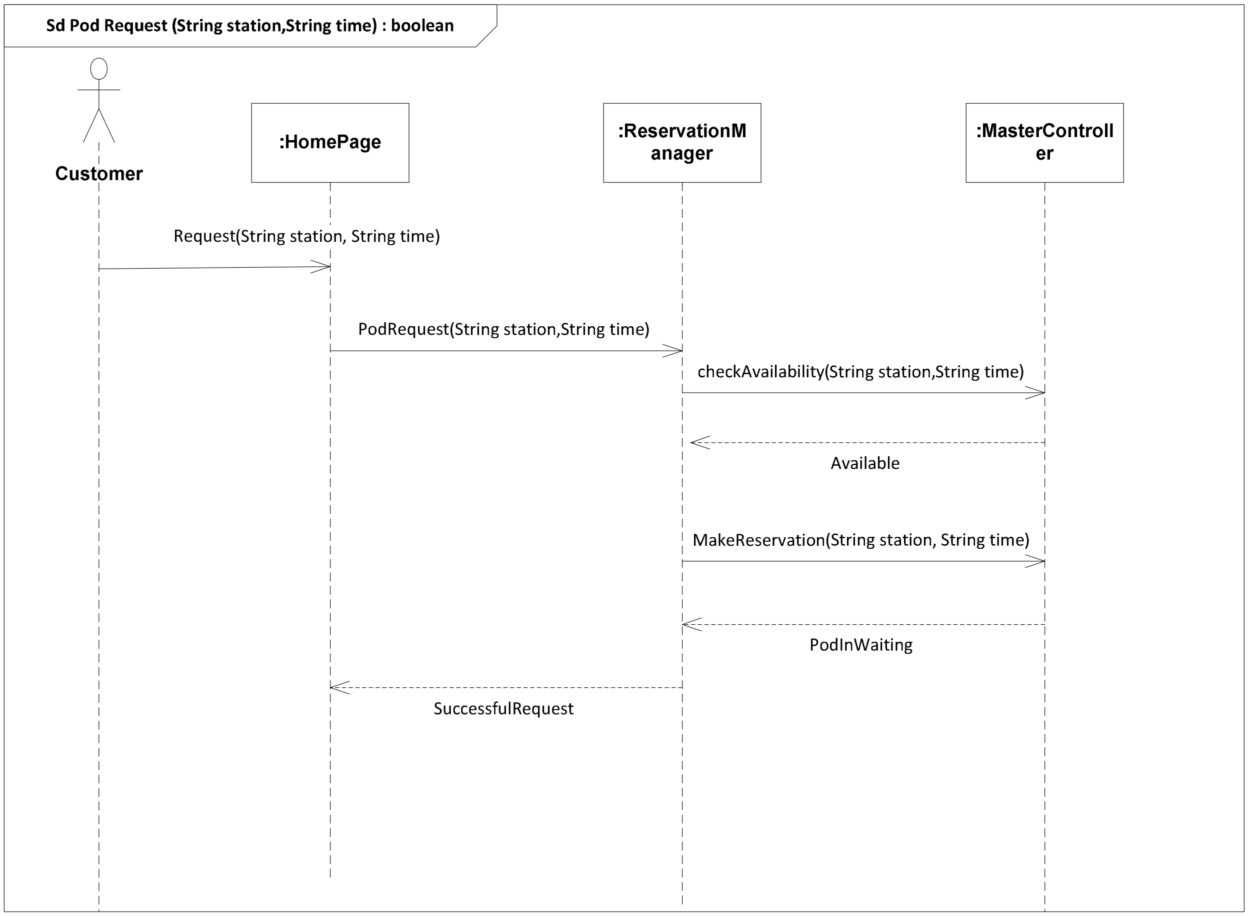


Figure 111: Reservation System Pod Request Sequence Diagram

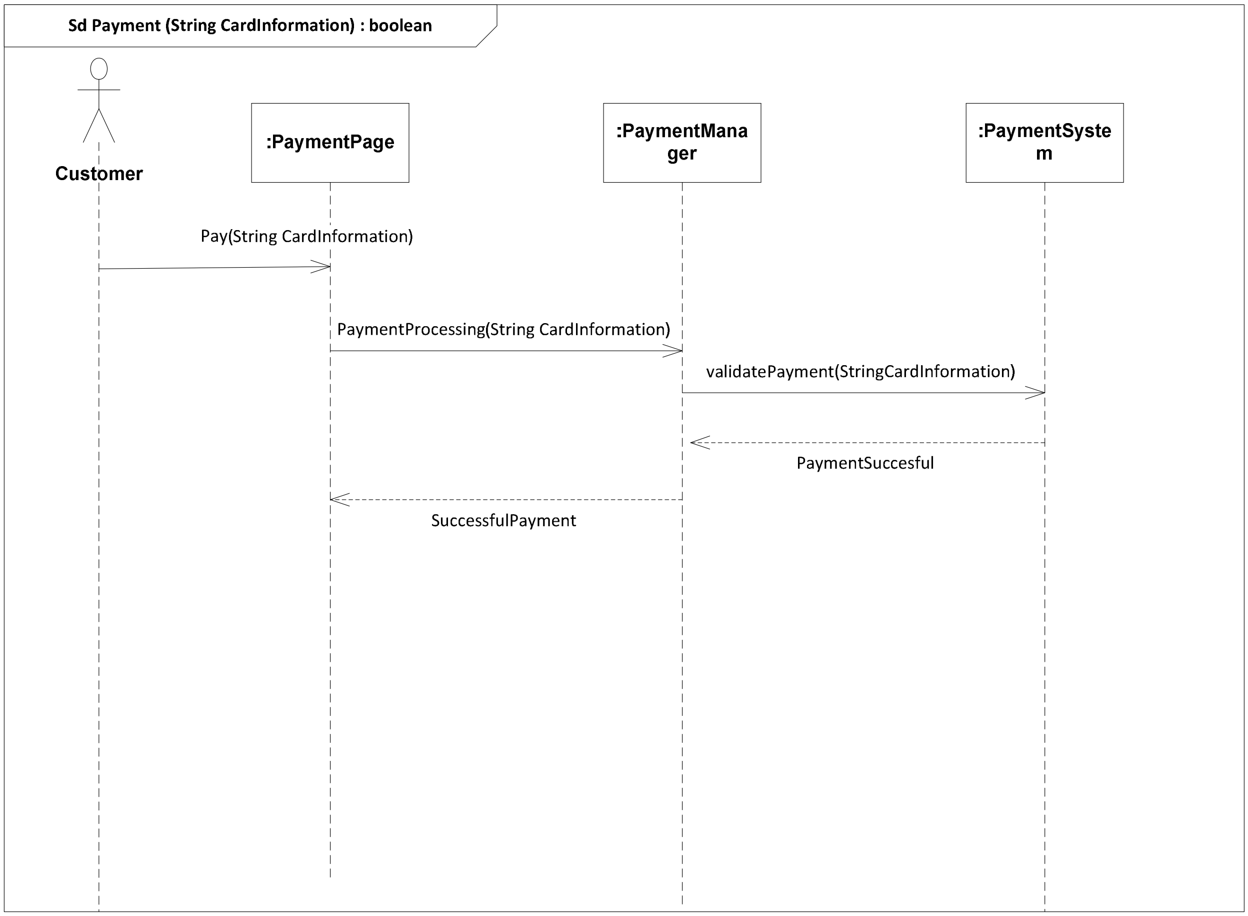


Figure 112: Reservation System Payment Sequence Diagram

System Modes and States

A high level examination of the system failure modes were considered during the design of this system. Any safety critical components must have redundancy to minimize life or injury threatening failures. Since the system was implemented to continue with limited functionality without the Master Controller and the Master Controller plays a major role in handling alerts, the failure modes were divided into two categories, the Master Controller is available, and unavailable.

Chapter 11: Twelfth Scale Model

A one-twelfth scale (1:12) model of this design has been constructed to prove some of the technical choices made for a real system. In places, this scale model dramatically deviates from the primary design.

Cabin

Due to the complex design of the cabin and a tight budget, 3D printing was the best choice to create an accurate 1/12th scale model for testing. All three pods, model shown below in Figure 113 were created in three sections, top, bottom front and bottom rear. The model was sectioned in this manner for ease of access to the electrical components that lie within and size limitations on the 3D printer.

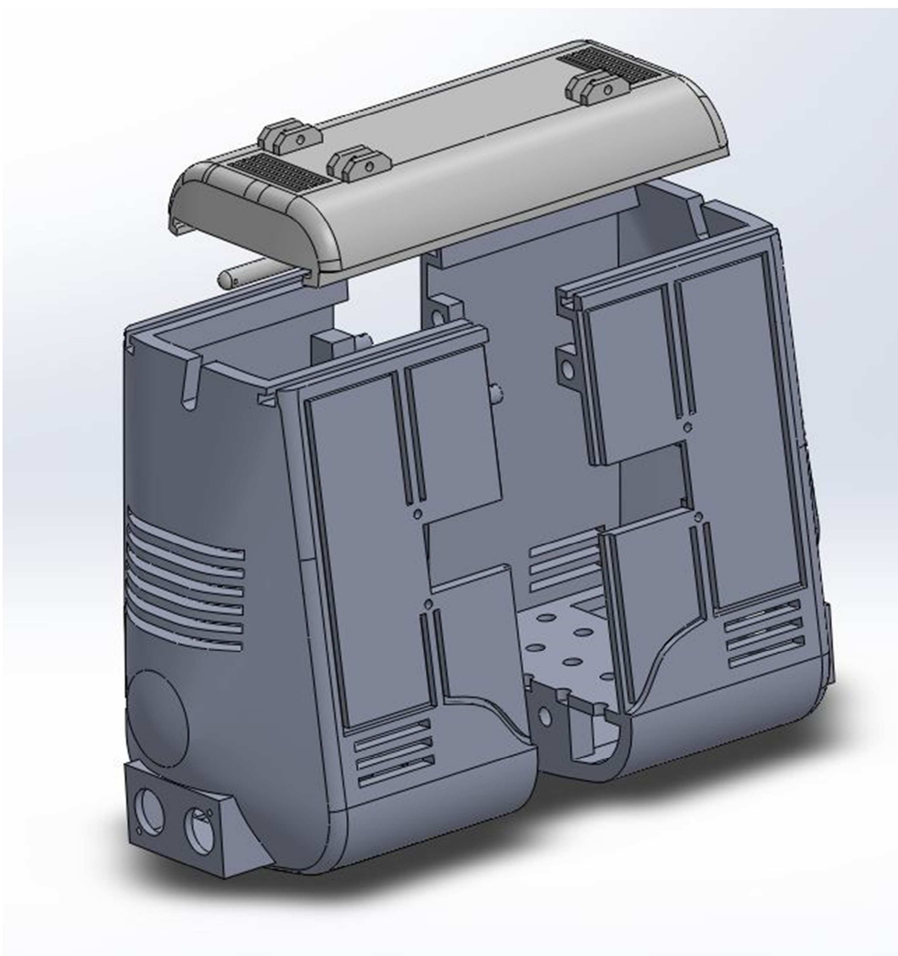


Figure 113. 3-D model used for printing the 1/12-scale cabin

The bottom front and bottom rear components snap together through the use of a pin and hole system as seen in Figure 114. The top slides into place using grooves that are located on the tops of the bottom halves. The top is secured by cotter pins.

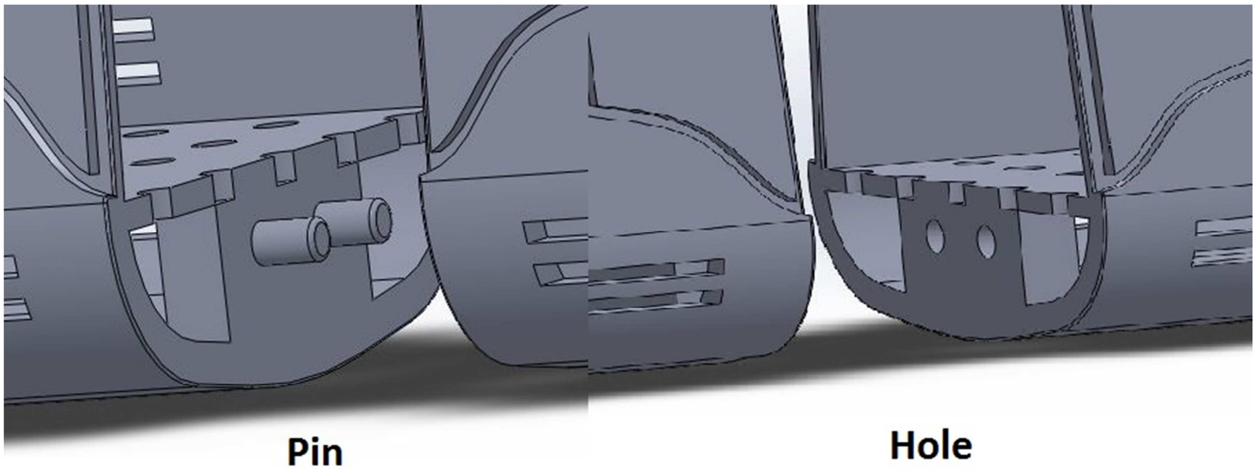


Figure 114. Pin and hole system ensures the pod stays secure

Table 24: 3-D Printed Model Dimensions

Component	**Dimensions**
Top	7.70 in. L x 3.59 in. W x 1.61 in. H
Bottom Front	5.09 in. L x 4.63 in. W x 7.09 in. H
Bottom Rear	4.67 in. L x 4.63 in. W x 7.09 in. H
Interior Floor	7.84 in. L x 4.13 in. W

Each piece has a uniform wall thickness of 0.25 inch, which provides enough rigidity while not consuming excess material.

Accommodations for Controls Hardware

Holes and cavities were required to be implemented into the scale model of the pod in order to house the controls and electronics hardware. These include:

- (2 ea.) ElecFreaks HC-SR04 Ultrasonic Range Finder
- (1 ea.) Hitachi HD44780 LCD Display Controller

- (3 ea.) TT Electronics OPB70WZ Reflective Object Sensor
- (2 ea.) Standard RGB (Red-Green-Blue) 5mm LED

SolidWorks software was used to model the holes and cavities for the hardware after each piece listed in Table 24 above was measured. Note that the above list does not include the various controllers and boards that are mounted on the "floor" of the pod.

First, the "floor" of the model's interior houses the controls boards and other hardware. In order to provide adequate cooling and decrease weight, holes were created and then patterned out. This allows air to pass through from underneath for cooling.

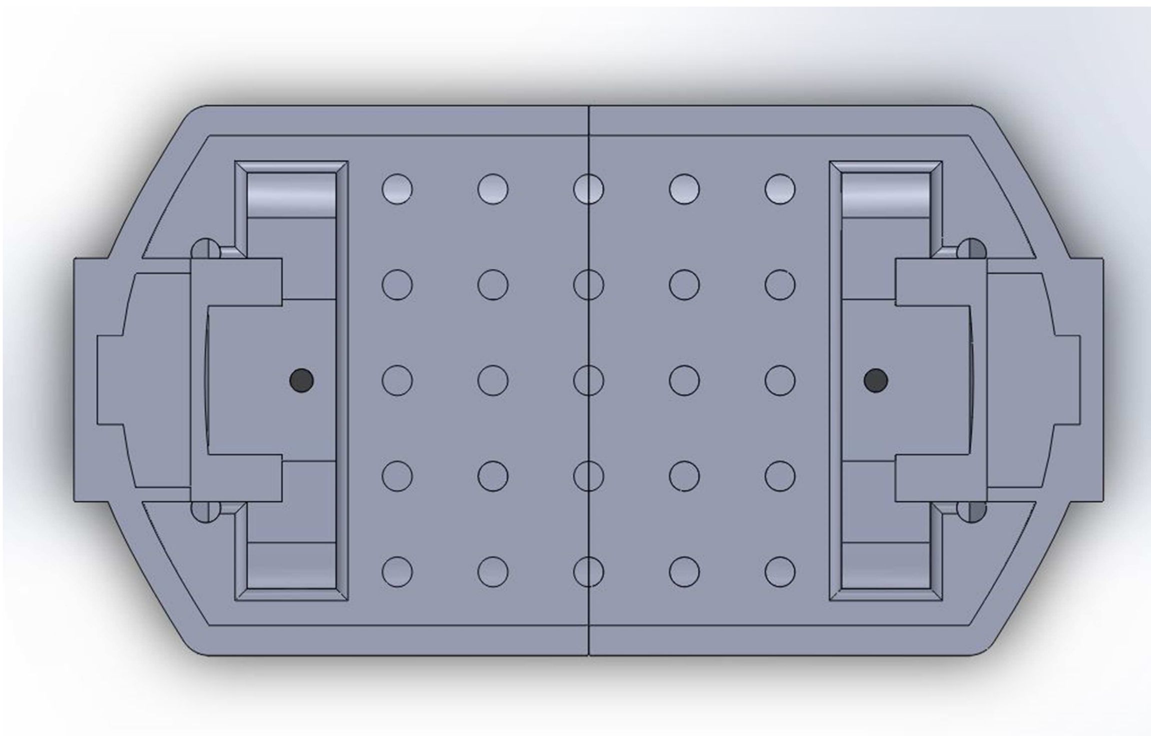


Figure 115. Top view of "interior floor"

The two HC-SR04 Ultrasonic Range Finder sensors are located on the bottom of each nose cone. An extension was created on the nose due to the fact that the two circular sensors on the module must be fully exposed in order to operate correctly.

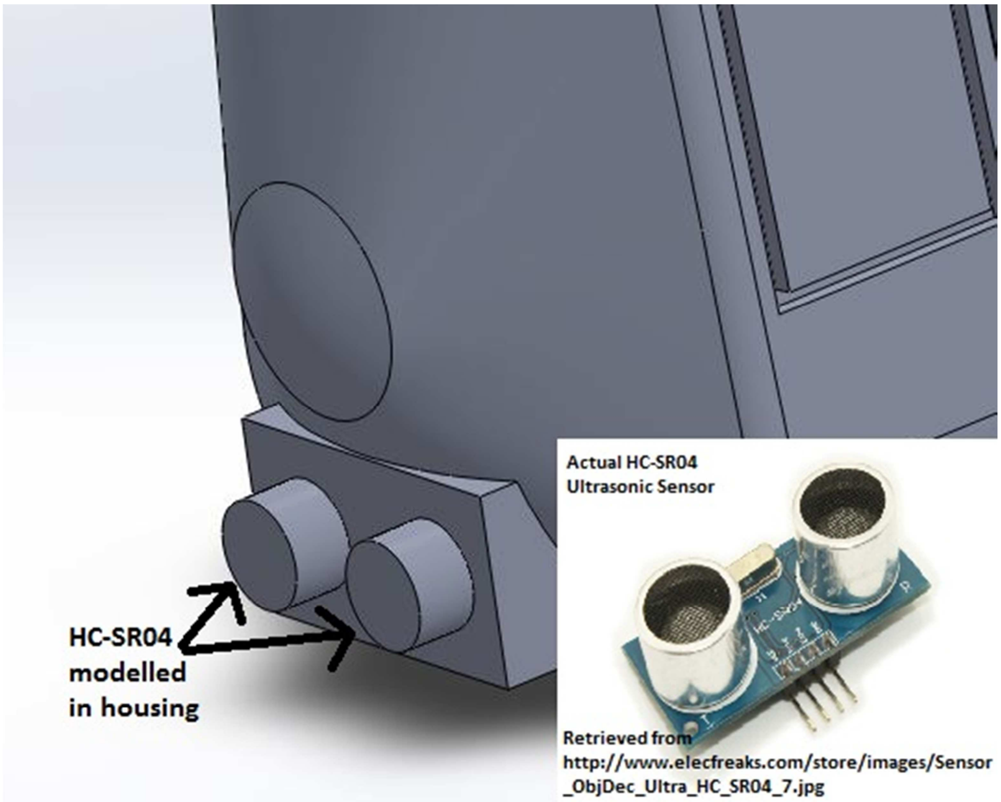


Figure 116. Accommodations for ultrasonic range sensors (HC-SR04, 2011)

In addition, the inside of the extension was designed so that it would be easily accessible and would accommodate the pins as well.

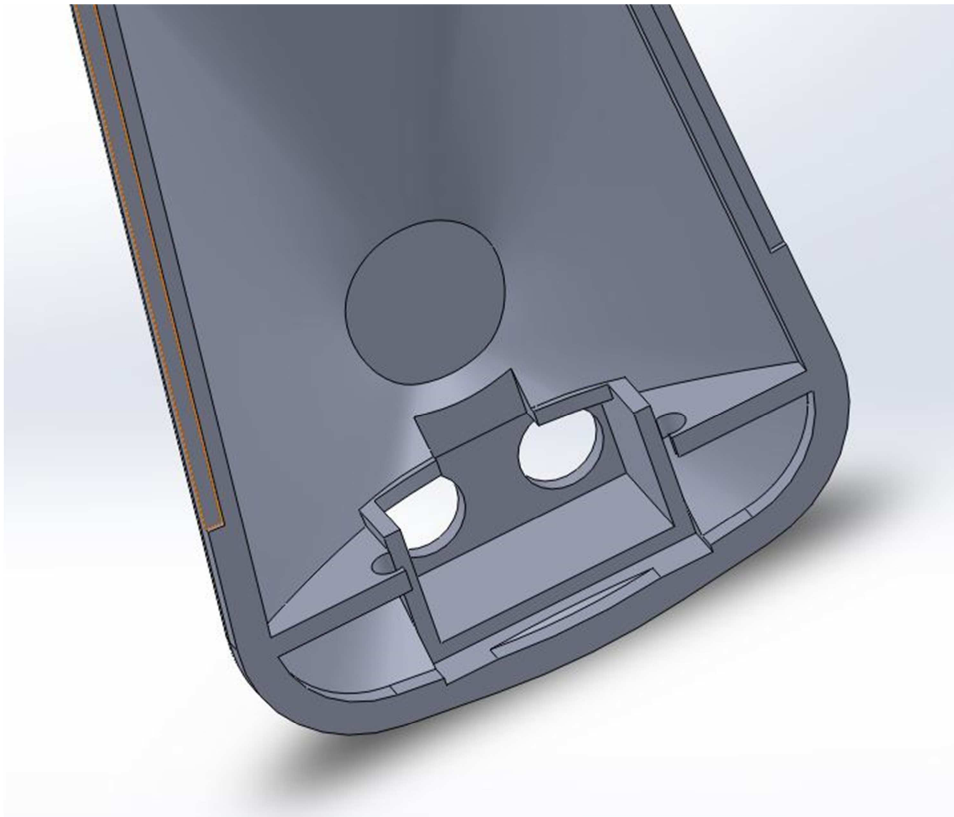


Figure 117. Interior view of ultrasonic sensor housings

One HD44780 LCD Display Controller is used for each pod, which shows the pod's status. A hole was simply created on one side of the pod with the appropriate mounting holes as well.

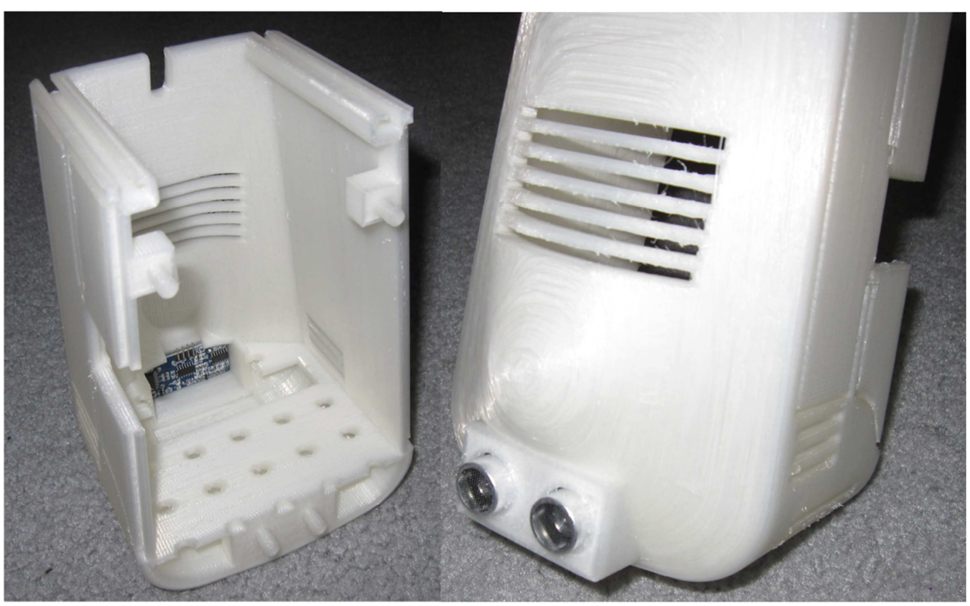


Figure 118: Ultrasonic sensor in model housing

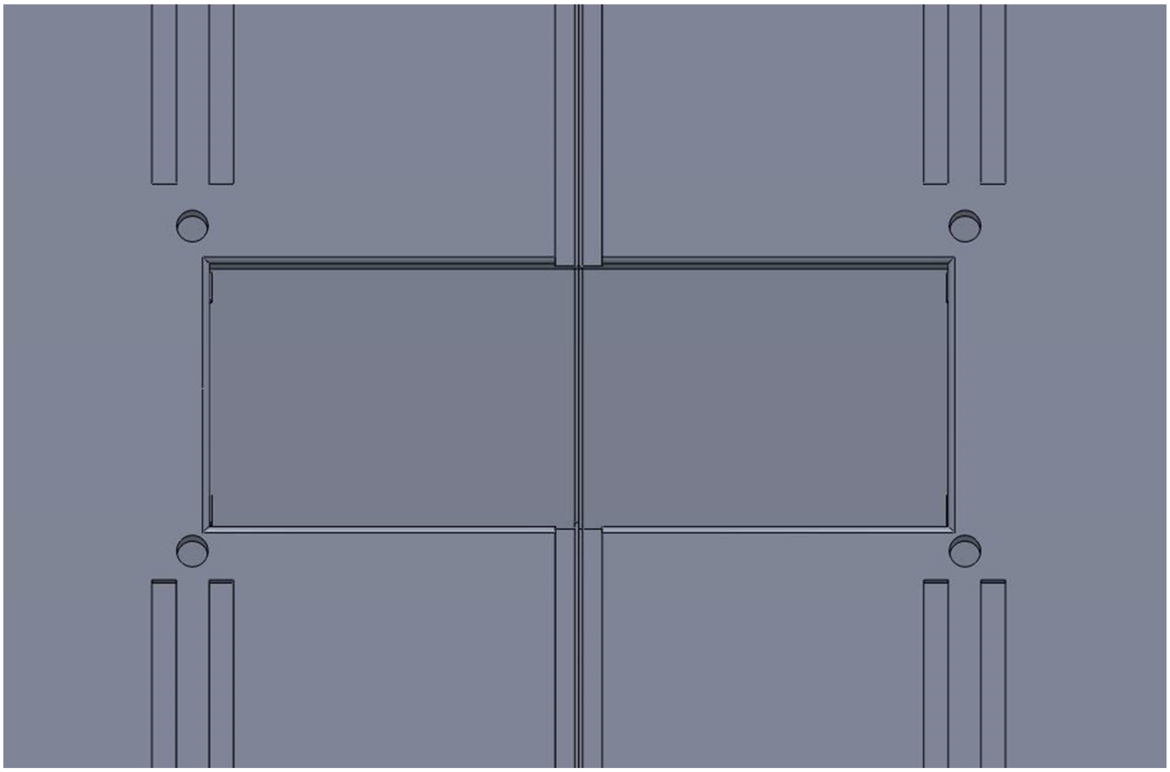


Figure 119. Cut out for LCD Display/Controller

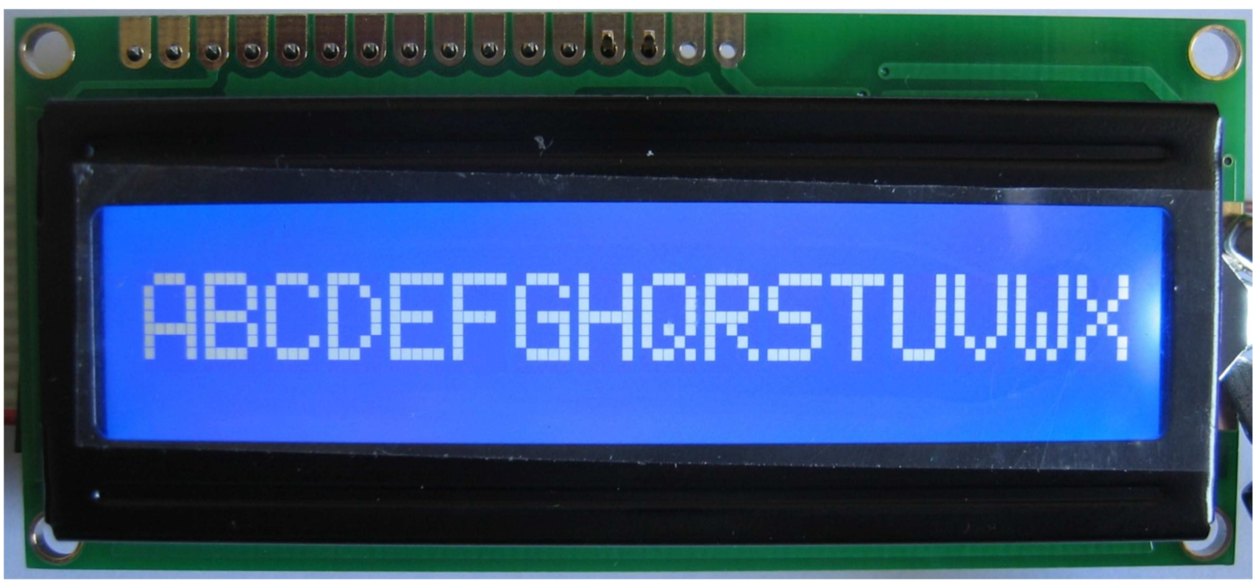


Figure 120. Actual HD44780 LCD Display (16x1 HD44780 Blue LCD, 2013)

One OPB70WZ Reflective Object Sensor is used for each pod, though two more can be added for redundancy.

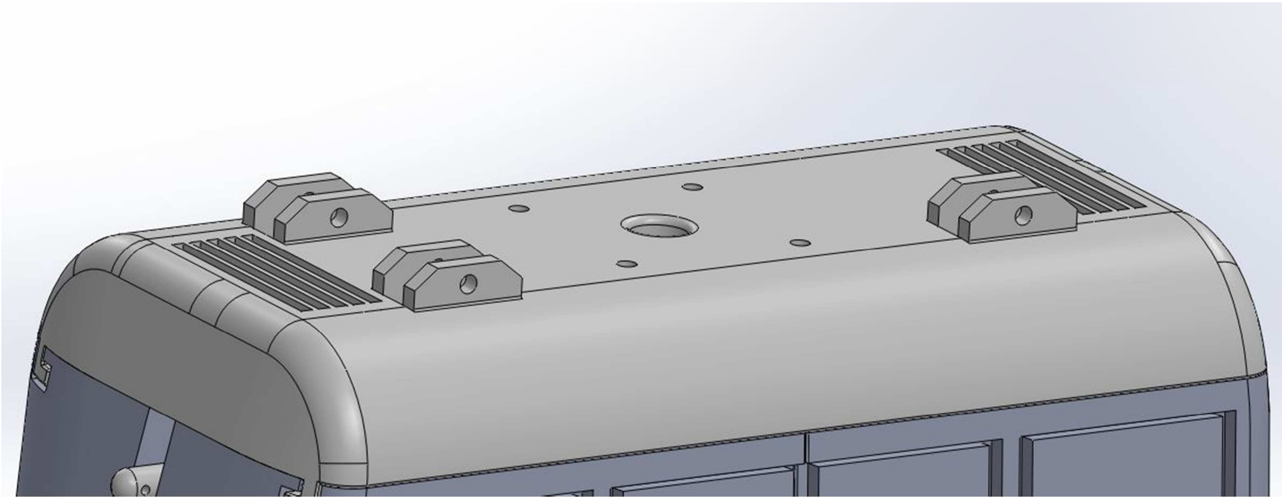


Figure 121. Mounts for Reflective Sensors

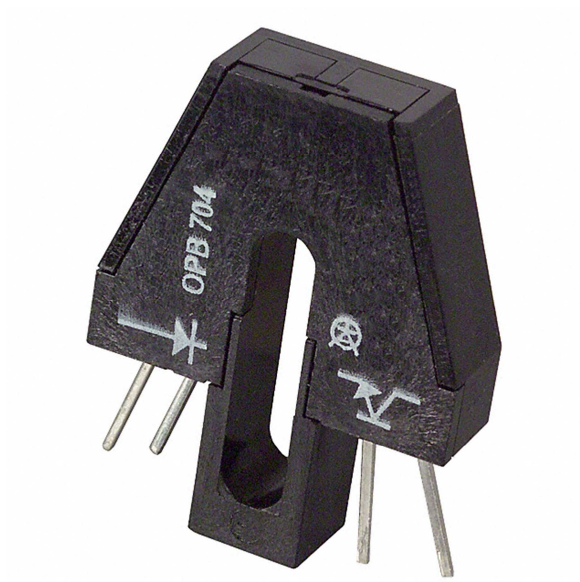


Figure 122. OPB70WZ Reflective Sensor (OPB704 TT Electronics/Optek Technology | 365-1091-ND | DigiKey, 2013)

The mounts for these sensors are located on the roof, or the pod top, so that the sensors can determine where along the guideway the cabin is.

Lastly, two holes were created at "belly" of each bottom half for RGB LEDs. These LEDs show the status of the pod.

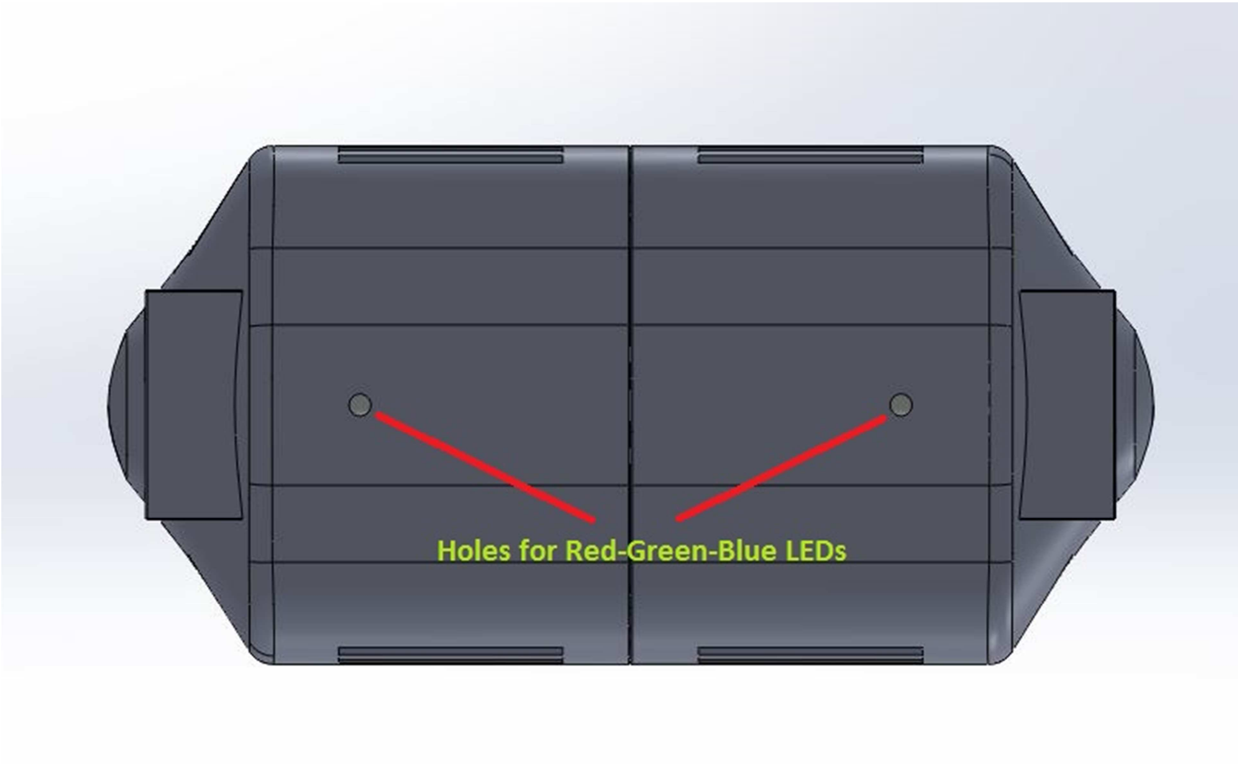


Figure 123. Holes for status RGB LEDs

Fabrication of the Model Hardware

A local project workshop called TechShop was chosen to create the scaled model because of the fact that they have state-of-the-art desktop MakerBot Replicator 2 3D Printers (TechShop San Jose, 2013).

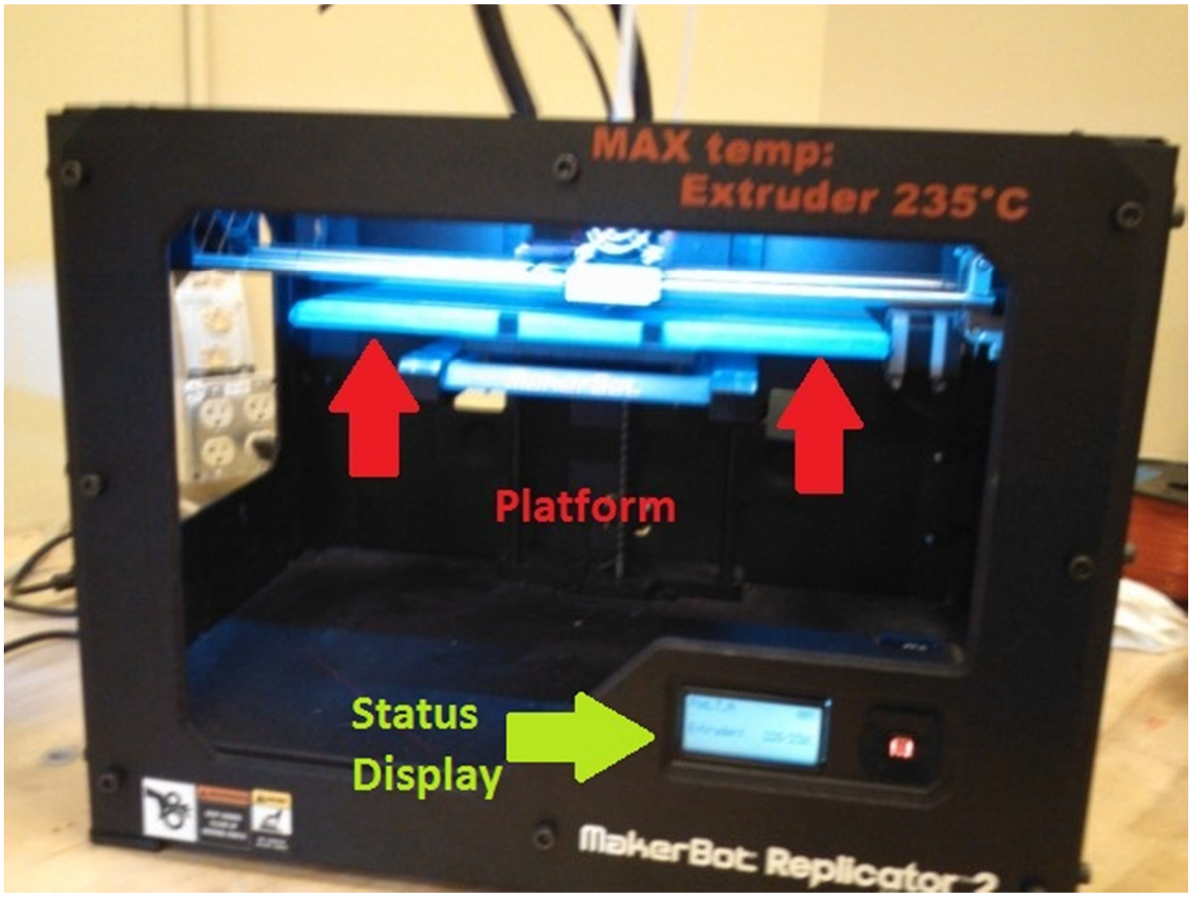


Figure 124 MakerBot Replicator 2

This machine is capable of printing to a fine resolution of 100 microns, or 0.10mm (MakerBot Replicator 2 Desktop 3D Printer, 2013). This is beneficial because of the fact that many of the features for the controls hardware, as well as for the assembly of the pod, must be accurate for proper fit. In addition, the machine can accommodate pieces up to 11.2 in. L x 6.1 in. W x 6 in. H.

Materials

The scaled model was printed using Polylactic Acid (PLA) material. PLA is an eco-friendly and biodegradable plastic that is derived from corn starch (MakerBot, 2009). As this project focuses not only on improving traffic congestion, but decreases our carbon footprint, PLA was the obvious choice to use to print the model. In addition, compared to ABS plastic, PLA is harder and better for larger objects (like ours) because of the fact that PLA does not warp and crack (MakerBot, 2009). However, as a result of this, PLA is more brittle rather than ABS which is ductile.

Each cabin, consisting of three total pieces (two bottom halves and the top), uses approximately 1 kg of PLA. This includes the sacrificial scaffolding structure that is used to build the pieces upon, as well as any other structures used in the construction process.

Disadvantages

Although 3D Printing is an excellent form of rapid prototyping, there are some drawbacks with it. For the specific machine that was used, some of these drawbacks include, aesthetics and printing time. In regards to aesthetics, it seems that with the MakerBot Replicator 2, contours do not come out well. Examples of this can be seen on the nose-cones of the pod. One can easily see the many layers, as well as the strands from the spool of PLA. Much “post-processing” was done in order to clean up the structures and loose strands. Printing time can be a disadvantage, especially if a part needs to be finished in a specific amount of time. The bottom halves of the scaled pod took approximately 24 hours each to print, while the top took about 8 hours.

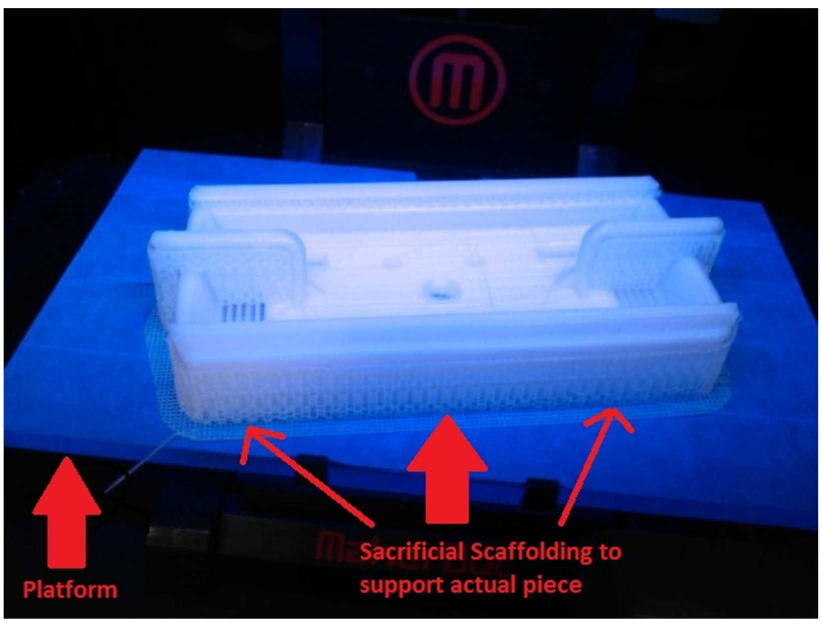


Figure 125. Pod top being created with structure underneath

More expensive 3D machines allow for quicker printing time with better quality and aesthetics as well. These machines can also eliminate any major need for “post-processing” and the need to remove structural supports. This cuts down on time as well and can be used almost immediately. Due to a very limited budget, the project could not afford to print using one of these machines.

Model Bogie Design

In order to provide a visualization aid to the conceptual design of the bogie, a working scaled prototype was designed and built. Although this bogie was designed to show the concepts of the full-size system, many full-size features were omitted due to size constraints.

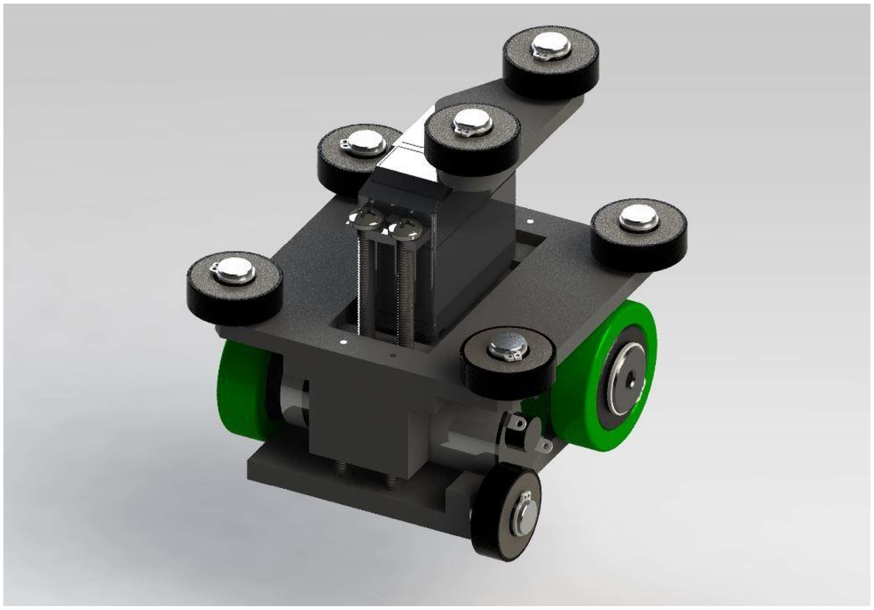


Figure 126 Rendered CAD Model of Scaled Prototype

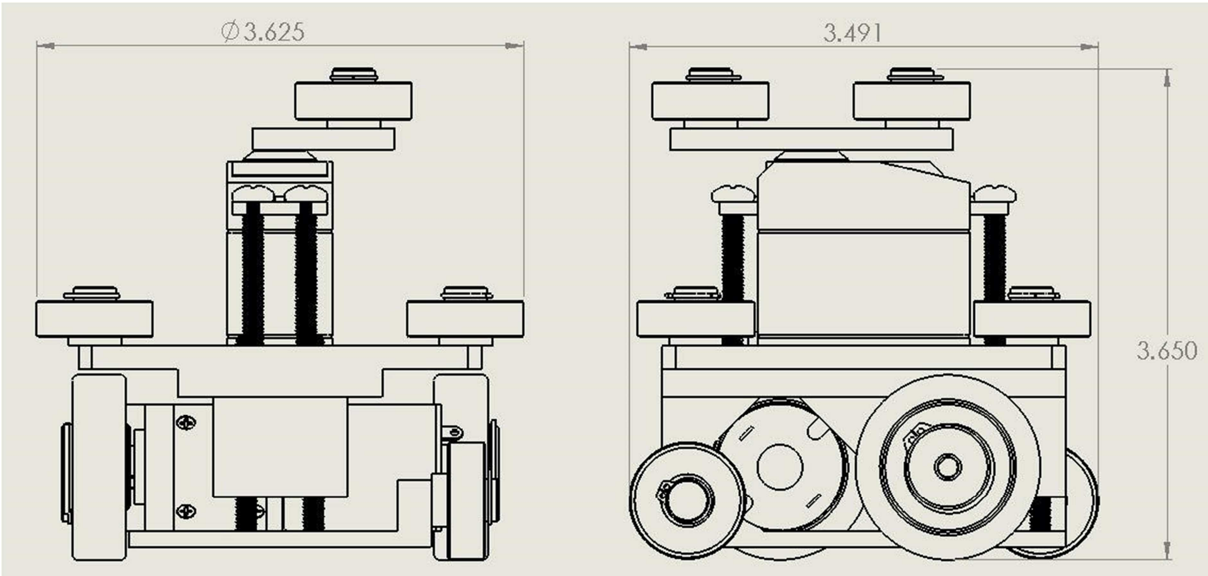


Figure 127 Overall Dimensions of Scaled Prototype

Chassis:

With size being the limiting factor in the chassis design, it was crucial to choose a material that would adequately support the full weight of the cabin and electrical components enclosed within.

Aluminum was chosen as the structural material for our first iteration of the scaled bogie due to its availability and workability. After spending copious amounts of time machining the donated aluminum, it was determined that 3-D printing the three test bogies would both be both a more efficient use of time and structurally sufficient (for this scale).

However, the ABS plastic utilized by 3-D printing machines to produce parts was weaker than the aluminum used in the first iteration, so some minor adjustments to the scaled bogie design had to be made. Additional support structures were added to the design which reinforced its structural integrity and allowed the 3-D printed miniature vehicles to replace the first prototype bogie.

The chassis itself is composed of three main parts; the base plate, the motor mount, and the bearing guide. Each of these parts were printed separately and then assembled.

Baseplate:

The baseplate is a simple design composed of a flat plate with two rectangular features extruding from either side. These rectangular extrusions are in which the support bearings are mounted. In the center of base plate is a rectangular recess and through hole in which the support/connecting rod is placed to connect the bogie to the cabin. The final revision of the baseplate includes a thicker bottom dimension. In order to maintain the clearance of the wheels, DC motors with an offset shaft were used.

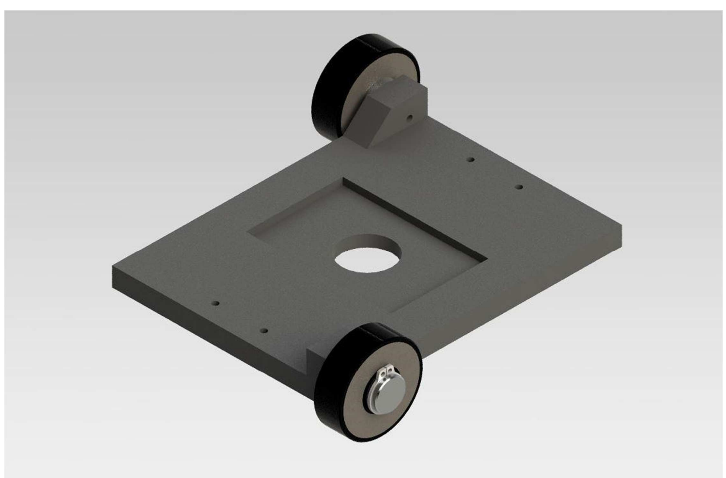


Figure 128 Rendered Baseplate

Motor Mount:

Securing the motors in place is an innovative structure that operates similarly to a v-block, which is used to hold work pieces during various machining processes. This structure operates by utilizing compressive and frictional forces to arrest the geared motors in their asymmetrical orientation. The motor mount is also on which the switching mechanism is attached. This mechanism is bolted to the top of the mount which is made accessible by an opening in the center of the guide plate.

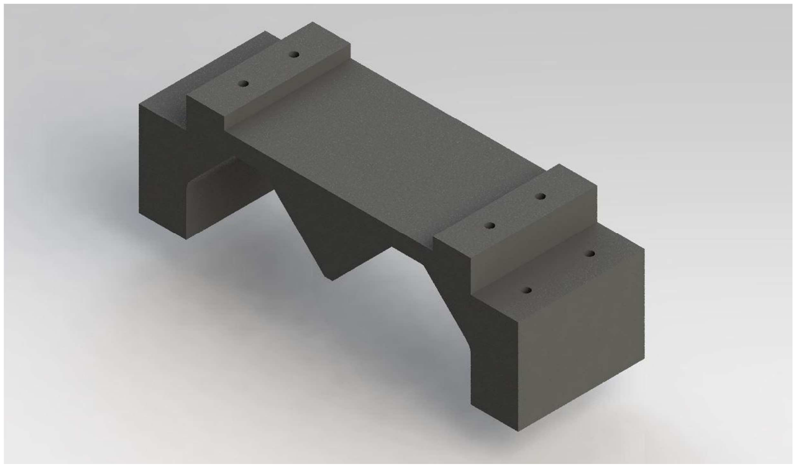


Figure 129 Rendered Custom V-Block Structure

Guide Plate:

The top plate, or guide plate, was designed to attach four bearings (two on either side) that would guide the bogie straight down the track.

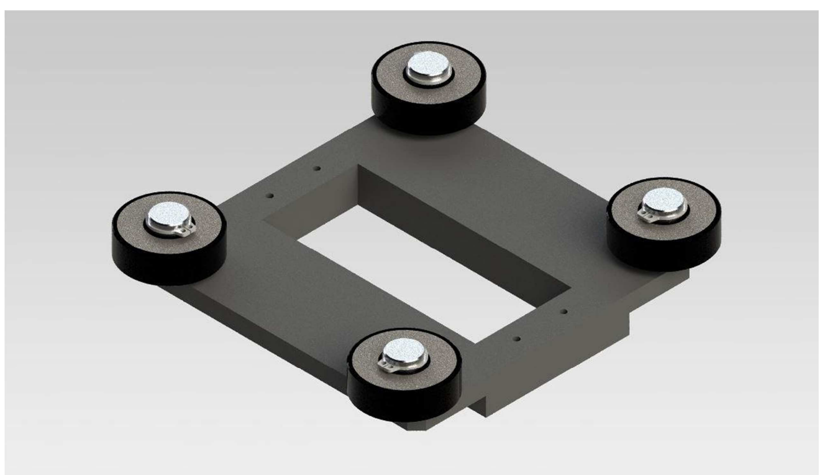


Figure 130 Rendered Guide Plate

Motors:

Realizing that a scaled LIM propulsion system would prove too challenging to manufacture given the team's allotted time and available resources, two small DC geared motors were used to provide the motion in our scaled propulsion system. Due to size limitations, the maximum number of geared motors that would fit into this scaled bogie design was two. In addition, the two geared motors had to be installed in an asymmetrical orientation in order to properly fit within the scaled footprint. The motors were chosen based on their torque and RPM ratings to ensure they would be capable of propelling the scaled system at a proportional rate that would represent the full-scale system. The motor specifications are shown in **Error! Reference source not found.**.

Specification	Value
Rated Voltage (VDC)	12
Terminal Type	Solder
Current @ Max. Efficiency (mA)	145
Torque @ Max. Efficiency (g-cm)	300
Speed @ Max. Efficiency (RPM)	190
Operating Range (VDC)	4.5 - 12

Figure 131 Motor Specifications (Jameco Electronics, 2013)

Wheels:

Attached to each of the drive motors are custom wheels made out of urethane tires bonded to plastic hubs, the urethane softness provides the necessary traction to drive the bogie. In addition to these two drive wheels are two supporting wheels which are simply skateboard bearings. These support wheels ensure that the bogie remains stable while in motion and prevents it from unstable oscillations due to an asymmetrical drive system.

Figure 132 Urethane Tire/Plastic Wheel Assembly

Switching Mechanism:

To provide the switching a hobby servo motor was implemented to replace the complicated switching mechanism of the full-scale bogie. The 1/12th scale would have reduced the effectiveness of the original system if we were to manufacture our own custom mini switching mechanism.

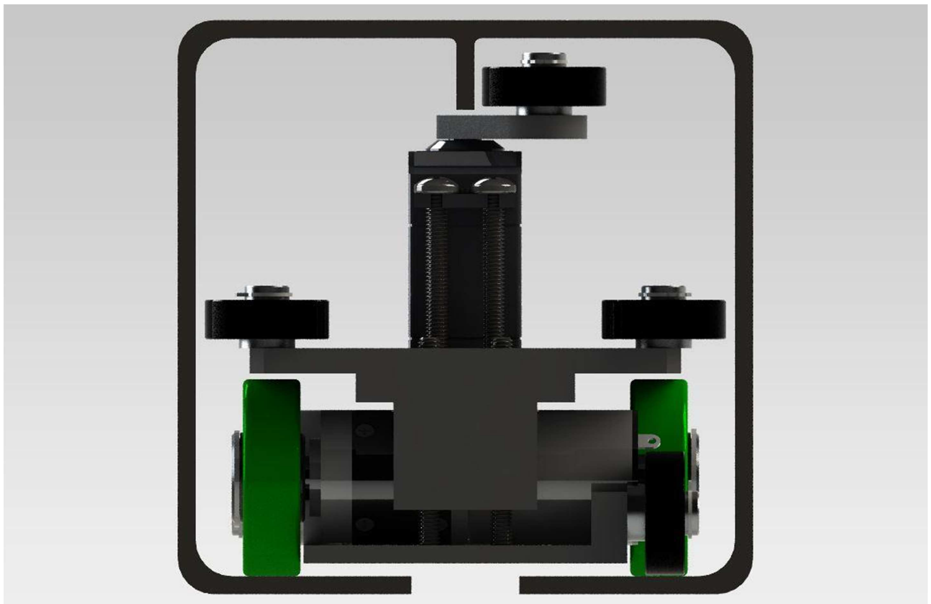


Figure 133 Rendered Model of Prototype in Guide way

The switching mechanism consists of a hobby grade servo motor, a custom 3-D printed servo horn, and a pair of ball bearings. When combined, these components serve to determine the direction of our bogie when it is in motion. As seen in the structural section of this report, the guide ways host a single divider placed in the ceiling of the channels. When a bogie approaches a split in the track, the hobby servo motor horn can be articulated to determine whether the bogie stays on its current path, or alters its course by turning and contacting the opposite side of the divider.

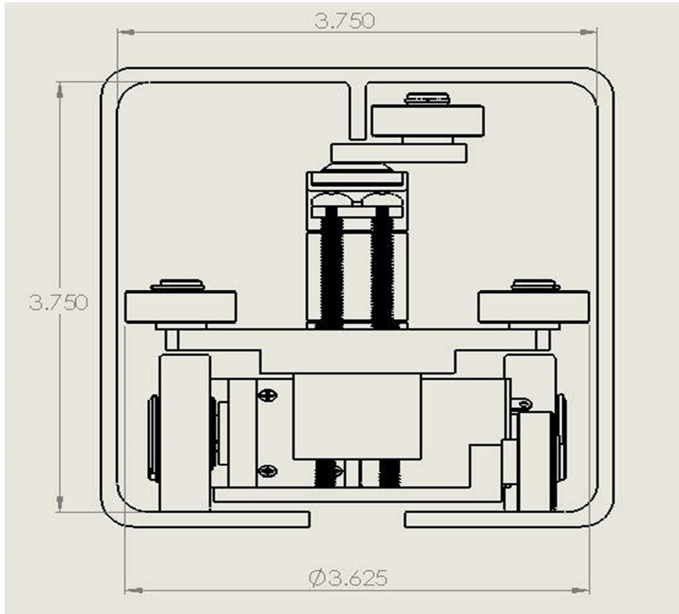


Figure 134 Overall Dimensions of Bogie in Guide way

Production:

The first prototype created was manually machined from aluminum. This model had the advantage of strength however it failed to meet expectations in key areas. The aluminum body had to be made with larger tolerances, meaning that each prototype created would be dissimilar than the next. Another disadvantage was the overall weight of this bogie was nearly twice that of a 3-D printed bogie. While the aluminum was machined by hand, other parts, including bolts, nuts, bearings, motors, wheels, hubs, and wire could be found locally. The completed aluminum bogie, without the servo, can be seen in Figure 135.

Figure 135: First prototype made from aluminum

The aluminum bogie served as a testing ground for the design. The creation of the bogie allowed the team to make hands-on refinements in the design. For example, it was discovered that a smaller width motor mount would allow for easier assembly, and more access to wires. As the bogie was aluminum, material could be removed, and the bogie could be tested again. This would not be as simple with a 3-D printed ABS bogie.

With the design updated, the ABS bogies could begin production. The first printed iteration was created using a Makerbot Replicator dual head extruder. Each part requires an hour and a half to print which translates to a minimum of five hours per bogie, allowing for preparation time.

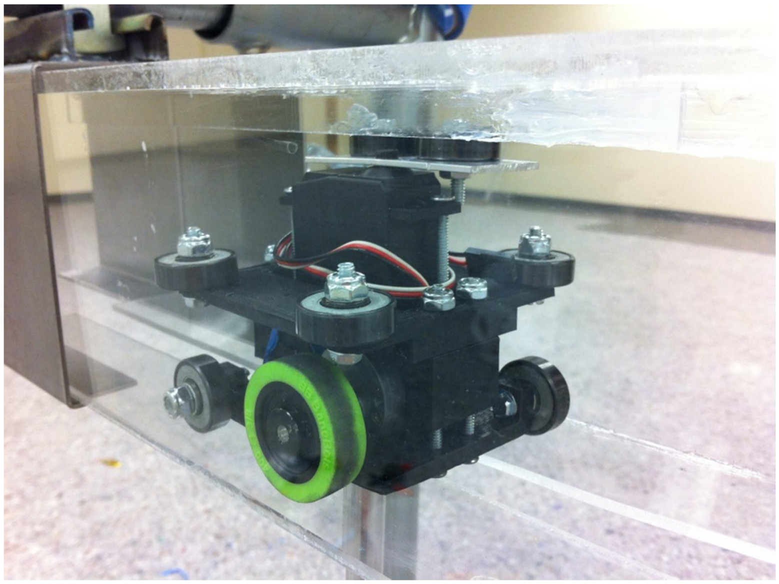


Figure 136: Initial ABS bogie during track testing

The first ABS bogie fit together very well (Figure 136), but each hole needed to be drilled to the proper size. Improvements were made in hole thickness, hole placement, structure support, and in the addition or removal of features. For example, ramping the front and rear of the base plate to reduce the possibility of contact with uneven track. The final two bogies exceeded expectations in strength, consistency, and execution. The completed bogies are shown in Figure 137.

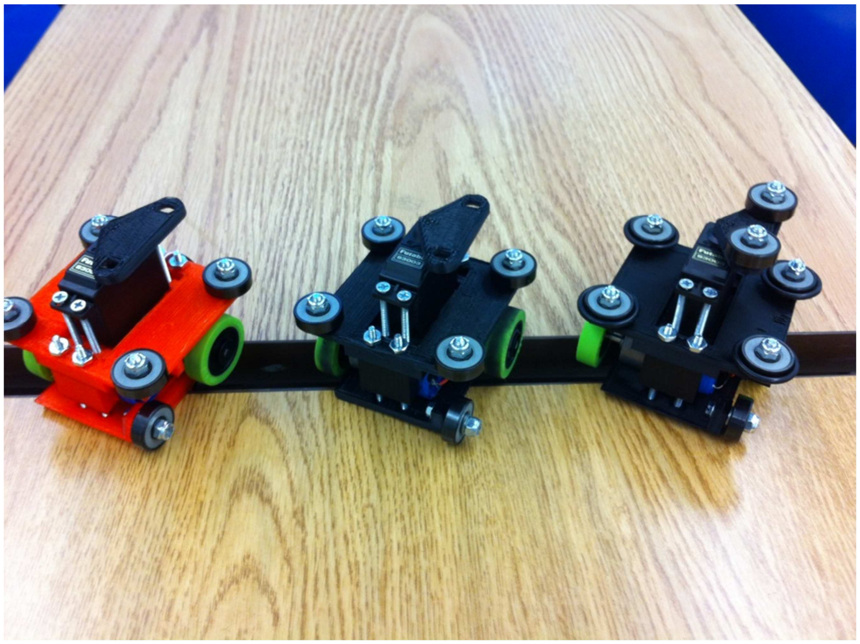


Figure 137: Three completed 3-D print bogies

Structures

Due to resource availability, size, and mobility requirements, the 1/12th scale model of the guide way and columns was designed to minimize cost and be modular for easy assembly and transportation. The layout of the track consists of three stations, two long straightaways, four corner curves, and several intersections wherever needed, as shown in shown in **Error! Reference source not found.**. The entire track is elevated to approximately 3 feet. Each corner curve of the track varies in radius so that the turning capabilities of the bogie and cabin can be tested. The three offline stations and other intersections can be used to test the control capabilities of the system.

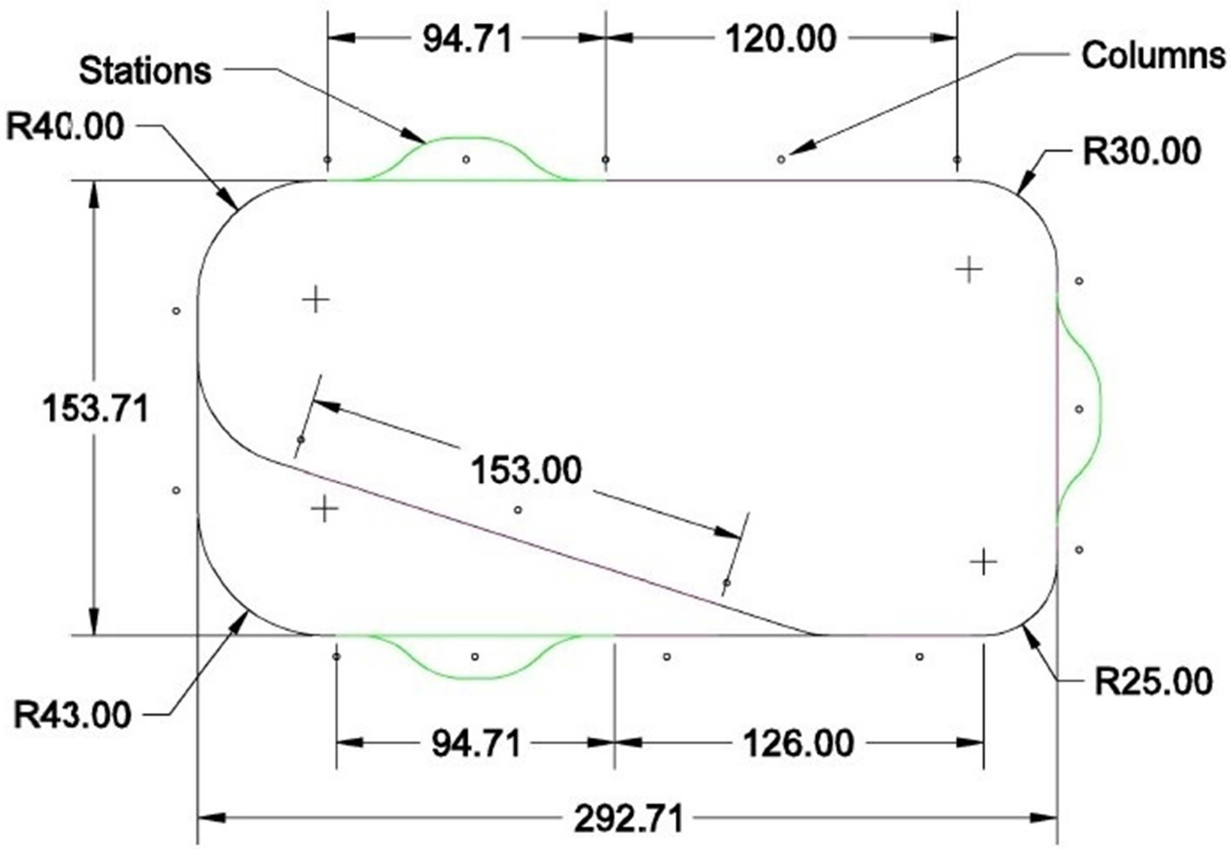


Figure 138. Track Layout of 1/12th Scale Model. Dimensions are in inches.

Guide Way

The straight sections of the guide way are made of 4 in. x 4 in. x 0.120 in. grade 50HS tubing steel. With help from Vander-Bend Manufacturing (Vander-Bend Manufacturing, n.d.), a middle slit was cut across the bottom length of the tube for the connection of the bogie and the cabin. Due to its complicated geometry, the station and intersection guide ways were cut from 1/8 in. to 1/2 in. acrylic sheets by a jigsaw cutting blade, and assembled together with acrylic glue. Plywood moldings were created and used along with 12” IRWIN clamps for easier assembly of the acrylic. A picture of the acrylic station guide way can be seen in Figure 139.

Figure 139: Acrylic Station Guide Way. This acrylic guide way was created from acrylic sheets of various thicknesses and assembled with acrylic glue, plywood moldings, and clamps.

Columns

A total of 14 columns were created in order to elevate the model above grade. Each column is comprised of a 1.5” diameter galvanized steel pipe, 3.5 feet long, , a 5 gallon bucket filled with concrete as a foundation, different shaped 1.5 in. diameter canopy fittings for the connectors, and the steel connectors themselves. The canopy fittings are adjustable, which accommodates for uneven floor levels, and allow the guide way to be set at a leveled height. A “T” shaped canopy fitting was used for the station guide ways, while an “L” shaped canopy fitting was used for the remaining guide ways, as shown in the CAD model in Figure 139 below. The steel connectors were made from bent sheet metal, with U brackets welded on. The U brackets are held up with the bracket connectors that hug the supporting arm protruding from the canopy fittings, as seen in Figure 141.

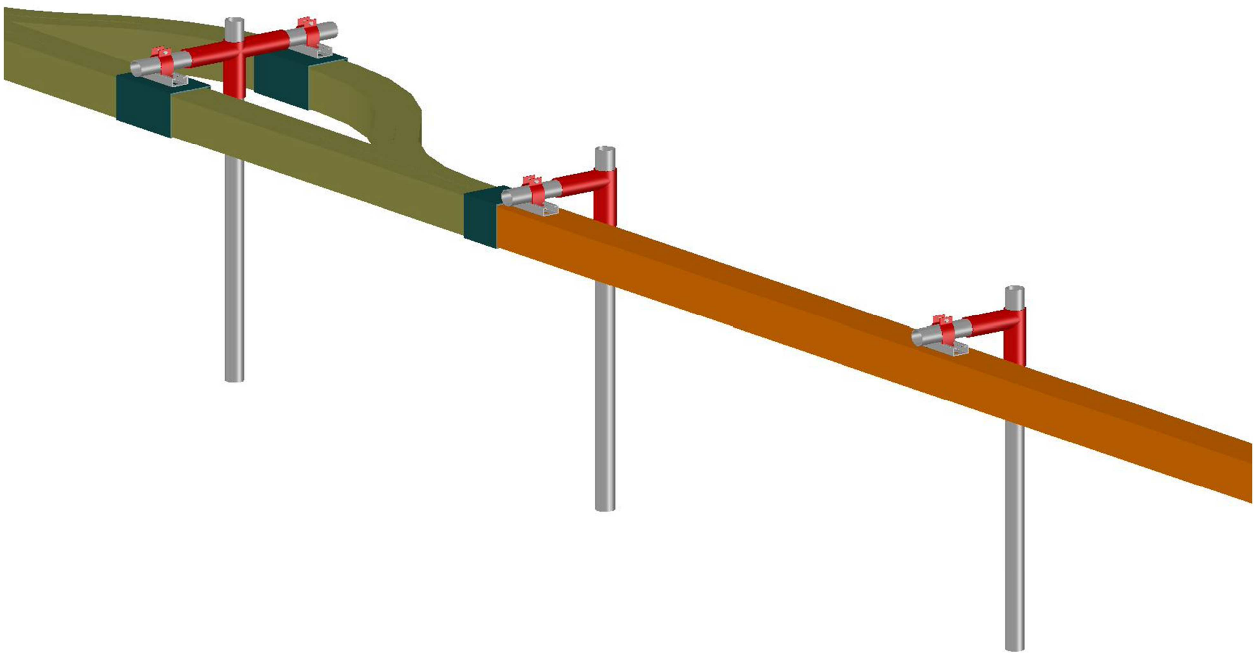


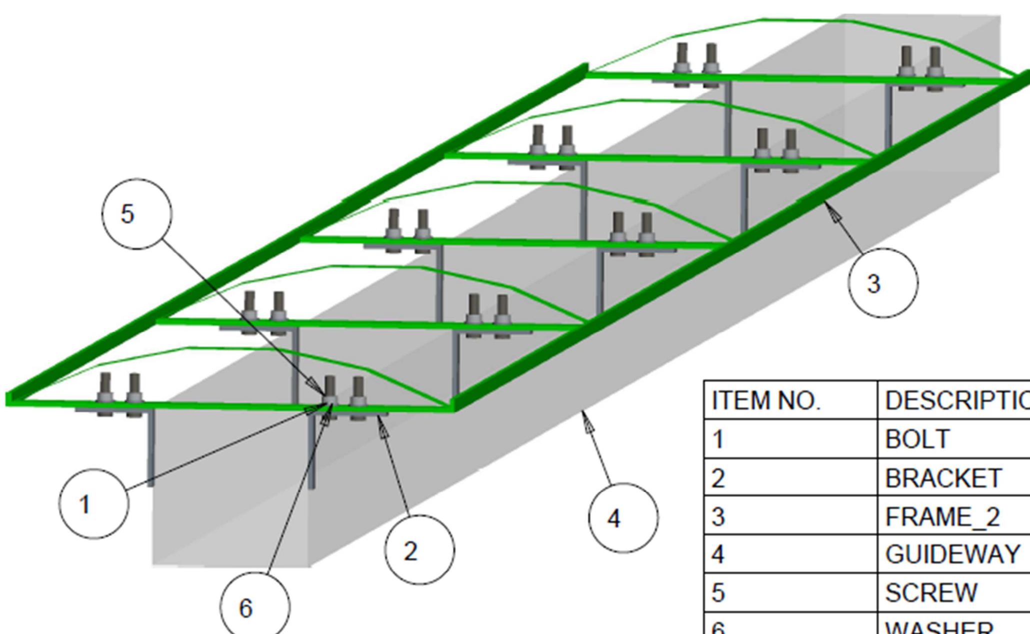
Figure 140. CAD model of a station and straightway. The red components represent "T" and "L" shaped canopy fittings, orange represents the steel straightway, light green represents a station, and dark green represents the connectors.

Figure 141. Example of an L shaped canopy fitting with U bracket. The supporting arm protrudes from the L shaped canopy fitting, and holds up the guide way via the U bracket.

Prototype Solar Support Structure Design

The solar support structure design criterion is for the structure to be rigid and easy to install and uninstall. In addition, the structure is to be designed to support one Solopower SFX1-i flexible lightweight PV module (reference **Error! Reference source not found.** for module specifications). Due to the length of the module (10 feet), the frame must be rigid enough to prevent any unwanted bending. The weight of the module (5 lbs.) is negligible so the frame must only support itself. The installation of the structure to the guideway must take a minimal amount of time. The idea is to reduce the labor cost associated with installation if this model would be built at a full scale. The criterion of easily uninstalling the structure is important so that future work, and/or re-location, can be easily done.

Making the frame out of steel gives the rigidity needed to prevent any unwanted bending, thus steel was chosen as the material for the structure. There were two initial designs as shown in Figure 142 and Figure 143. The first design shown in Figure 142 was determined to be inadequate for several reasons. The first reason is that the SFX1-i module was not flexible enough to maintain the curvature that the frame was designed for. The second reason is due to the unwanted stress on the module due to the curvature. The third reason is because there were too many parts for assembly which made it time consuming to install. The fourth reason is that the structure would be directly on the guideway, which would put unnecessary weight on the guideway. The final and main reason is that the length of the frame (10 ft.) is too big to meet the maximum clearance from column to column (5 ft.).



ITEM NO.	DESCRIPTION	QTY
1	BOLT	20
2	BRACKET	10
3	FRAME_2	1
4	GUIDEWAY	1
5	SCREW	20
6	WASHER	20

Figure 142: First initial design of the prototype solar support structure and assembly. Several reasons why this was an adequate design, mainly due to the frame being too long to meet the maximum clearance from column to column.

The second design shown in Figure 143 was an improvement from the first design, but didn't meet the installation and uninstallation criteria. In the second design the curvature and the brackets are eliminated. The module is now directly on the top surface of the horizontal beams, eliminating any stresses on the module. The brackets in the first design were removed and replaced by two longer brackets welded to the horizontal beams 5 ft. between each other. These brackets would rest on four ¼"-13 x 4" galvanized coarse thread carriage bolts that would be clamped on the horizontal column beam that holds up the guideway. The idea was to have the frame directly elevated (floating) above the guideway. This design was not adequate for a several reasons. The first reason is that the support structure was not accessible, in terms of getting in the way of other work being done to the guideway . Another reason is that it wouldn't take a minimal amount of time to install and uninstall. The last reason is the possibility of any horizontal bending of the bolts.

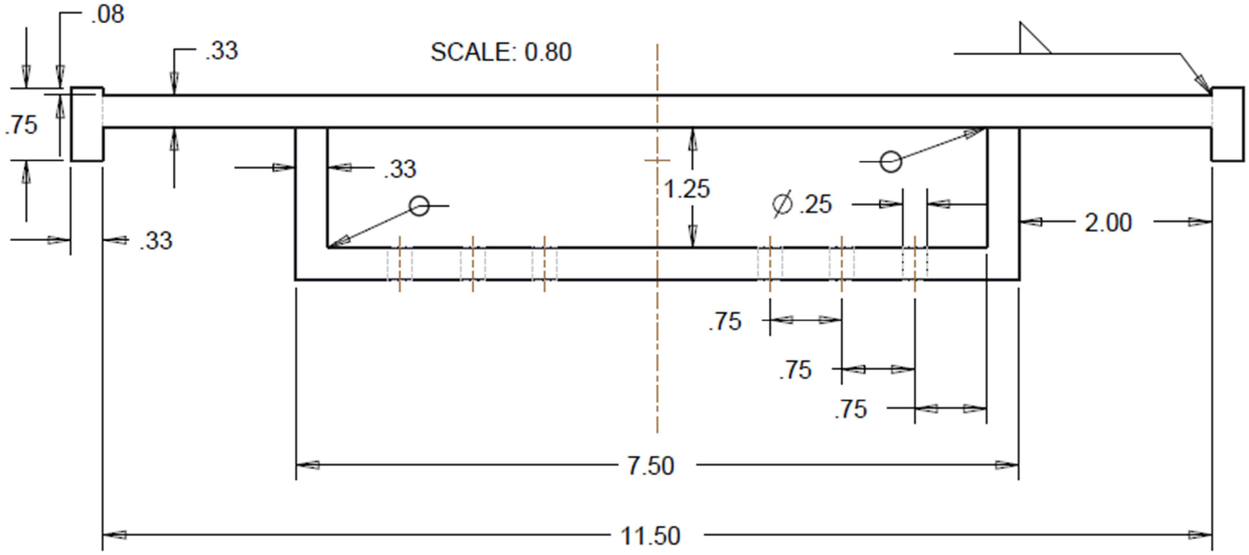


Figure 143: Second design of the prototype solar support frame with two long welded brackets

The final design shown in Figure 146 minimizes components making it easy to install and uninstall. The two long brackets in the second designed are replaced by a 1/8 inch thick flat plate shown in Figure 144 with two holes to fit two 3/8"-20 x 2 ¼ " hex bolts in which the frame would rest. The frame is supported by a mount shown in Figure 145 with two holes angled at 32° to give the frame the needed tilt angle that would maximize energy production from the PV module. The long cylindrical pipe from the mount goes into to the vertical pipe column shown in Figure 147; this makes it easy to remove the whole structure from the guideway, making it easy to install and uninstall.

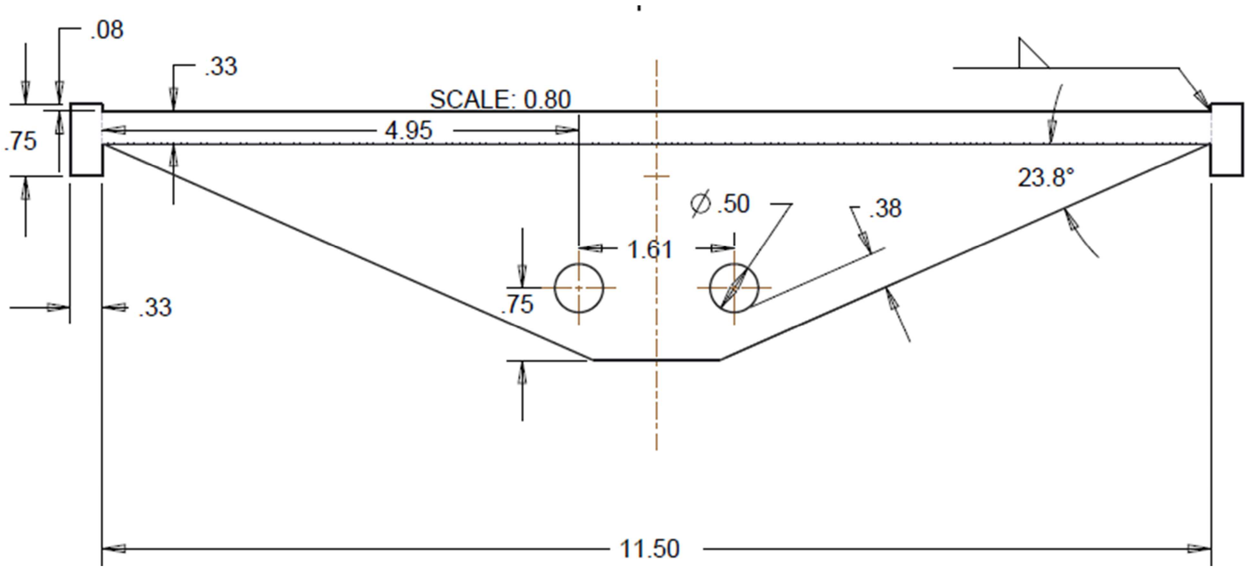


Figure 144: Final design of prototype solar support frame with 1/8" thick flat plate

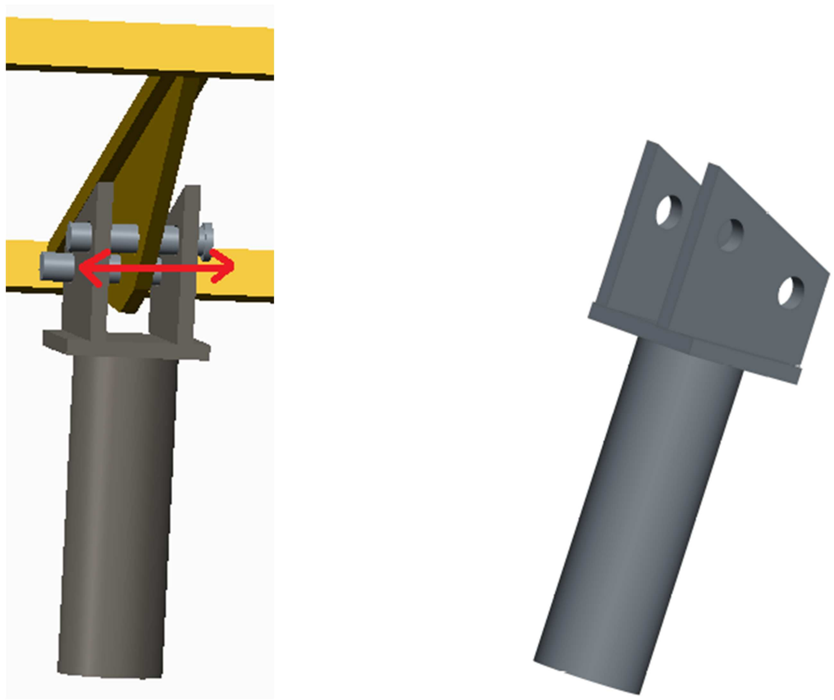


Figure 145: Frame mount support (right). Vertical plates are spaced to provide extra clearance for the 1/8" thick flat plate and move the frame horizontally as needed (left).

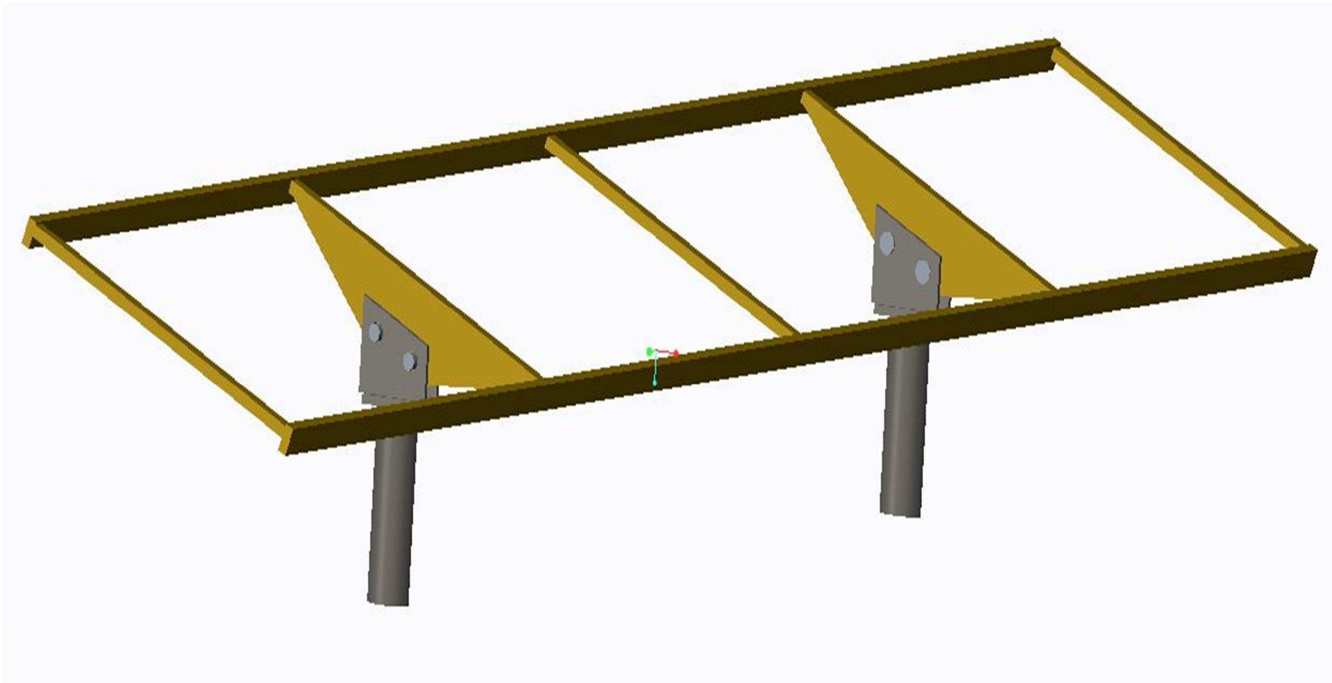


Figure 146: Final design of prototype solar support structure and assembly

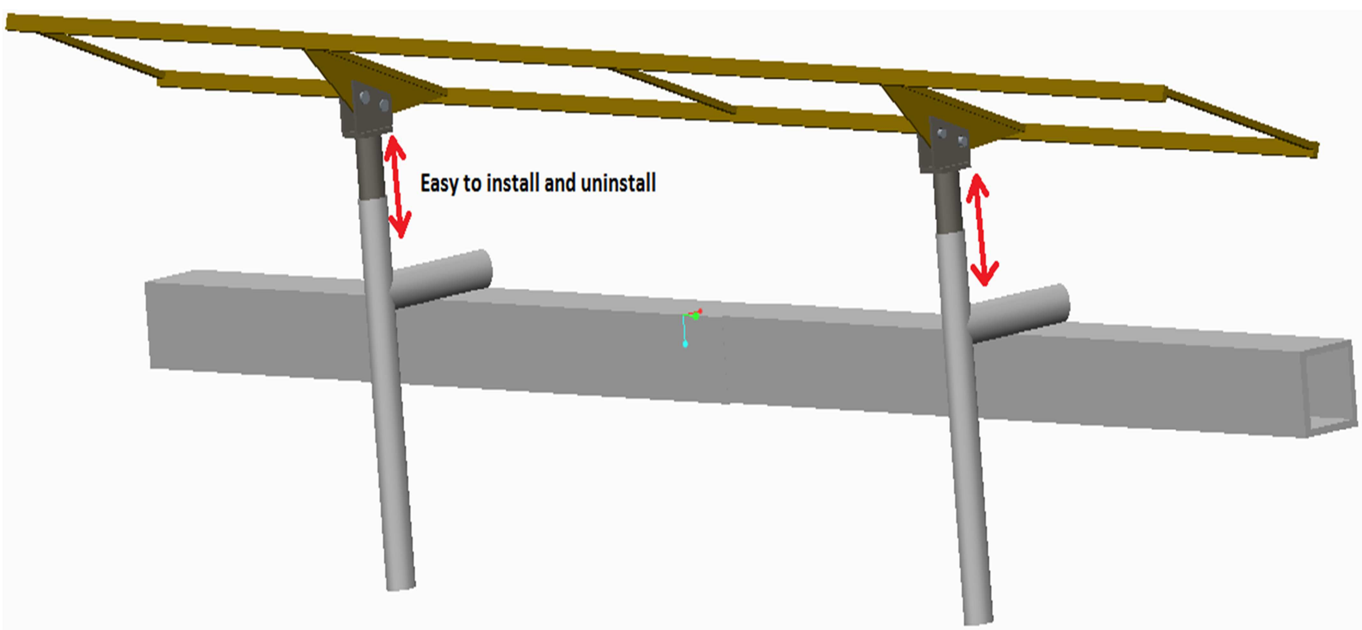


Figure 147: The cylindrical pipe fits in the vertical column pipe making the whole solar support structure sturdy. The whole support assembly can be easily removed by just lifting off the cylinders.

Figure 148: SFX1-i module mounted on frame. The module can be bonded to the surface of the horizontal beams of the frame is permanent placement is desired (the module in this case wasn't bonded to the frame so it can be easily removed and tested in an outdoor environment)

Note that the dimensions from Appendix D (CAD drawings) of the whole structure were modified to fit the donated material (in particular the mount structure). One can notice that the actual prototype differs slightly in dimensions from the CAD drawings. All material was donated by the SJSU MAE Department at no cost.

Control Systems

Asynchronous Event-Driven Message Framework

All of the controllers were designed using a developed framework to support asynchronous calls between services internal to the controller. A service is defined as an object with events that serves a specific role to make up the controller as a whole. Each service subscribes to interesting events of other services using a subscriber and publisher pattern. The services add additional functionality to the controller and are developed to operate independently of each other. Most of the functionality takes place within service handlers for subscribed events from other services and executed asynchronously with in a well-defined thread pool. The thread pool is handled by the underlying Boost ASIO library and all scheduling and execution is provided by an io_service object. A single io_service instance is shared among all of the services in the controller. Even though the io_service contains "service" in the name, do not confuse it with the service previously defined.

All events use a Data Transfer Object (DTO) to transfer data or "a message" between the services. When an event is raised, the DTO and reference to the sender is posted to the service's io_service object for each subscribed handler. All handlers are executed in any available thread within the thread pool.

Implementation

The control system is divided between several projects, EventFramework, SharedServices, Master Controller, Pod Controller, and Merge Controller. The EventFramework implements the asynchronous subscriber and publisher event pattern. SharedServices implements the basic functionality shared between all of the controllers, including the ServiceBase abstract super class and socket communication between controllers. The other projects implement the controller according to requirements.

EventFramework

The EventFramework is for implementing asynchronous events using the Boost ASIO library. The event framework uses a subscriber and publisher pattern, which is suitable for passing Data Transfer Objects between the services. The EventFramework uses Boost ASIO to manage the scheduling of handlers between multiple threads. ASIO implements the Proactor design pattern to handle the scheduling between available threads in a thread pool.

The EventFramework is for implementing asynchronous events using the Boost ASIO library. The event framework uses a subscriber and publisher pattern suitable for passing Data Transfer Objects between the objects. The EventFramework uses Boost ASIO to manage the scheduling of events between multiple threads. ASIO implements the Proactor design pattern to handle the scheduling between available threads in a thread pool.

The Proactor Design Pattern is implemented in Boost ASIO according to the following diagram:

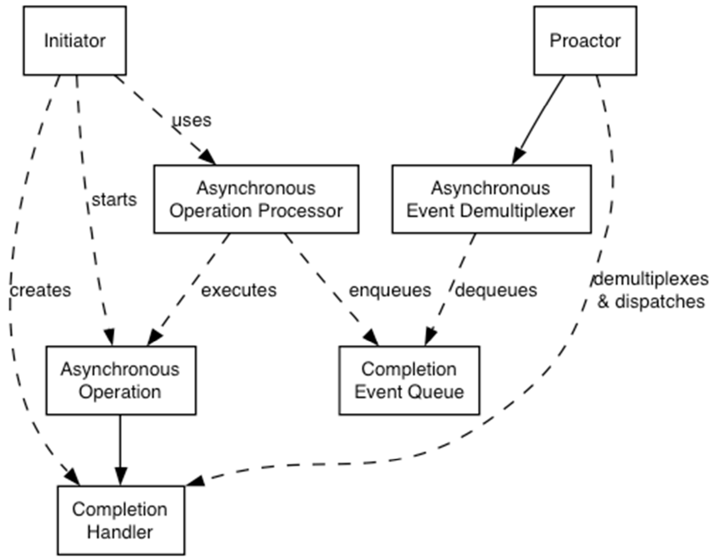


Figure 149: Proactor Design Pattern (Boost.org)

Completion Handlers are function objects created by the Initiator. The Initiator initiates asynchronous operations. The Asynchronous Operation Processor is used by the Initiator to either put the operations on the Completion Event Queue or execute the operation using Asynchronous Operation. On the other side, the Proactor calls the Asynchronous Event Demultiplexer to dequeue, in other word, to wait for an event to occur on the queue. This multiplexer then returns the result of the event to the Proactor. The main advantages of using this Proactor Design Pattern are portability, performance and scalability (Kohlhoff, 2008)

EventArgs

Is the base class of the Data Transfer Object (DTO) in the EventFramework messaging framework. For any raised event, an EventArgs object will be copied to the subscribed event handlers and executed in an available thread.

Event

The Event template class allows any EventArgs children to be invoked within an available thread.

SharedServices

The SharedServices are the basic services shared among multiple controllers in the system.

ServiceBase

The ServiceBase implements the basic service lifecycle states used to startup and shutdown the controller safely. Every Service incorporates four lifecycle methods, Initialize, Start, Stop, and Deinitialize. When a lifecycle method is called, it will raise the corresponding lifecycle event on completion (ie Initialize() will raise the InitializedEvent). Alert related events are also implemented, to allow for the SafetyService to easily subscribe and monitor all Services in the local controller.

ServiceManager

The ServiceManager manages the services and is responsible for handling the lifecycle method calls on all of the local services in the controller. When the ServiceManager begins initialization, a chain of events is started between all of the controller services. The ServiceManager initialization calls the initialize method on each service. Since the lifecycle event call backs are raised asynchronously after completion, the ServiceManager subscribes to each lifecycle event and makes calls to the next service in order within its handler. The chain of events continues until either all services are successfully initialized and started, or an error occurs and the startup fails.

It is important to note that the order of startup and shutdown are reversed from each other. For example, the first service to start becomes the last service to shut down. Also, the order in which the services are added to the ServiceManager may be critical for the system to startup successfully.

CommService

The CommService is responsible for communication between the controllers, and registering the controller with the Master Controller. During the start process, if registration is enforced the service will wait for registration completion before continuing the start sequence for the rest of the controller.

Registration takes place during the CommService start. A socket is opened to listen on a predefined multicast address for registration offers from the Master Controller. When the registration offer is received, the controller will respond with a controller ID and connection information to the Master Controller and wait for a response. If the response is successful, the controller continues the startup procedure. If the response is unsuccessful, the CommService will raise an error and prevent the controller from completing startup.

The state machine below shows the CommService states during registration.

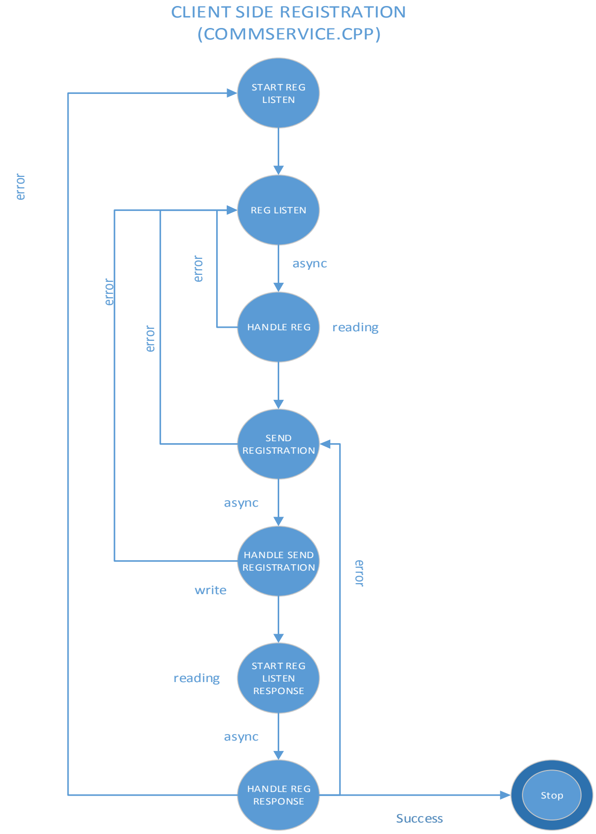


Figure 150: CommService Registration State Machine

After the registration is complete, message passing becomes available to the controller services.

All messages are received and sent through the MessageAvailable events and handlers supplied by the CommService. The types of MessageAvailable events available include, MasterMessageAvailable, PodMessageAvailable, and MergeMessageAvailable. Any service requiring communication outside of the controller raises their own MessageAvailable event subscribed to by the CommService. Any incoming messages from other controllers are sent internally through raising the CommService events. Any services subscribed to a CommService MessageAvailable event type will receive the message.

The EventArgs passed through the events are transformed according to the type of MessageAvailable event raised. Each outgoing EventArgs is transformed into a corresponding Protocol Buffer message using the objects in data.pb.cc. Protocol Buffer is then able to serialize the message in to an efficient structure for transmission across the network through the use of Unicast UDP.

On the receiving end of the incoming message, the operations are done in reverse of the outgoing. The packet data is deserialized through Protocol Buffer, and the corresponding

EventArgs is created. A MessageAvailable event is then raised and the EventArgs is transferred to any subscribed services.

ConsoleService

The ConsoleService provides a command interface to manually configure and control the Controller. The ConsoleService will require ownership of a thread while it is running. The user input statement (std::cin) and command loop will block the thread from finishing work. With some small parsing logic, new commands can be created to access internal controller resources. This could potentially be useful for debugging purposes.

ControllerDatabase

The ControllerDatabase is responsible for interfacing directly with the backend SQLite database. Any persistent data access is implemented through this class. Any additions of data in the ControllerDatabase, must also be implemented into the schema for the corresponding controller.

SQLite is used in this project to handle all database interaction between controllers and reservation system. SQLite is a relational database management system with open source in the public domain. The advantage of using SQLite is that it does not have a separate server process and is cross platform compatible. The database is read and written directly to ordinary disk files ("About sqlite." n.d)

In this project, SQLite is used to create a database of controllers and reservations. Master, Merge, and Pod controllers can access the database using functions implemented in ControllerDatabase and MasterControllerDatabase class. SQLite implements the normal SQL syntax for creating table, update, insert, etc. However, SQLite has its own syntax to retrieve row and column information from database queries (sqlite3_prepare_v2, sqlite3_blind, sqlite3_finalize, etc.). Each data object is implemented using the CRUD (Create Retrieve Update Delete) functions.

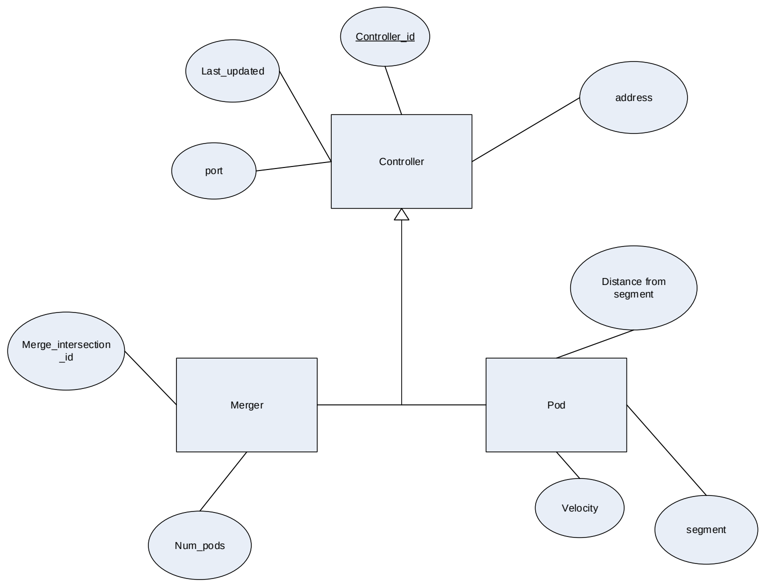


Figure 151: Controller Database Relational Schema

The schema above shows the available controller objects already implemented in the database. The schema supports tracking the status of the system and controller connection information for message passing.

The ControllerDatabase interface was still under heavy construction and needs additional information storage for the ControllerGraph.

ControllerGraph

All graph data is accessed through this class. The ControllerGraph will load the graph information from the database during initialization on startup. It also has the ability to serialize itself for sharing between the MasterController and PodController. At the time of this document, the ControllerGraph is still heavily under construction and may change in functionality.

Master Controller

The Master Controller is the primary controller for the entire system. The class diagram below shows the services that are the services used in the Master Controller and their inheritance from

ServiceBase.

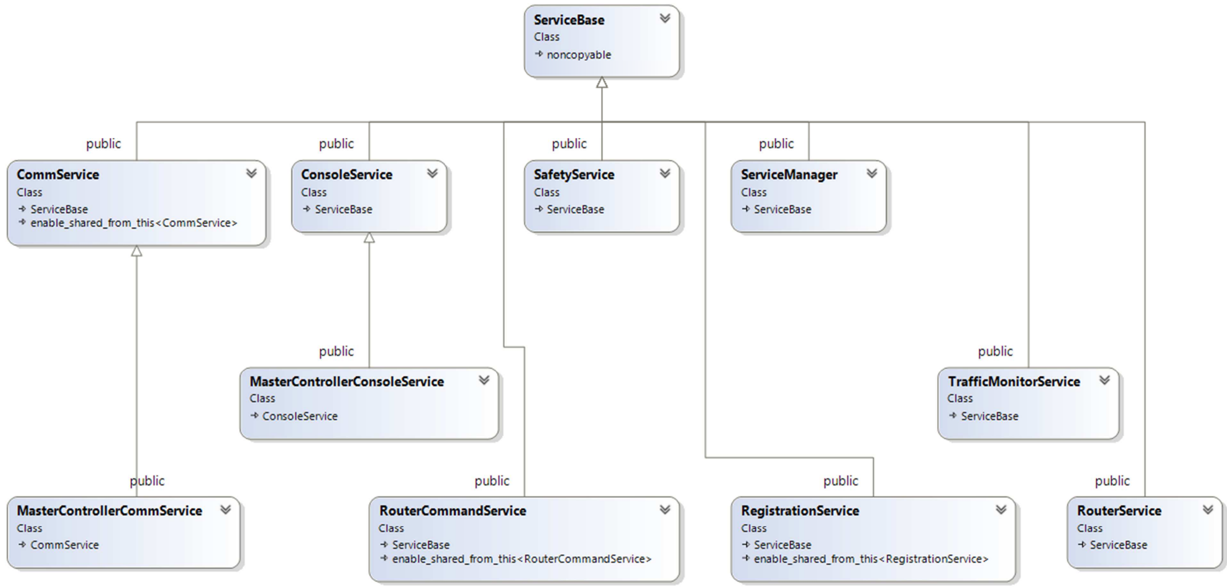


Figure 152: MasterController Services and Inheritance

MasterControllerCommService

The MasterControllerCommService disables the registration requirement for the CommService to start.

MasterControllerDatabase

The MasterControllerDatabase inherits from the SharedServices ControllerDatabase. The MasterControllerDatabase adds the ability to store reservations from the ticketing system. For any reservation request from the ticket system, a persistent record is stored through this interface.

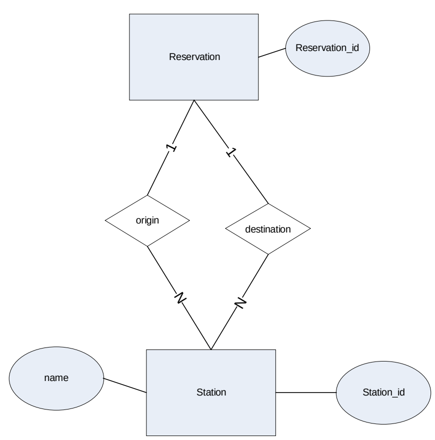


Figure 153: Reservation Database Relational Schema

The above schema was implemented to track the reservations received form the ticketing system.

MasterControllerEventArgs

The MasterControllerEventArgs inherits from the EventFramework EventArgs DTO. All MasterControllerEventArgs are specific to the Master Controller.

RegistrationService

The RegistrationService manages controllers entering and leaving the system. Any controller that needs to join the control system must register themselves before becoming functional within the system.

The RegistrationService uses a multicast broadcast to advertise where the Master Controller is located on the network. When a waiting controller receives the broadcast, controller ID and connection information are sent to the Master Controller. The Master Controller then responds whether the controller has been successfully registered.

To implement the protocol, two state machines were used to process the incoming registrations. One machine sends out a multicast advertisement within a specific time interval. The second state machine handles the incoming registration requests. The figure below shows the registration state machines.

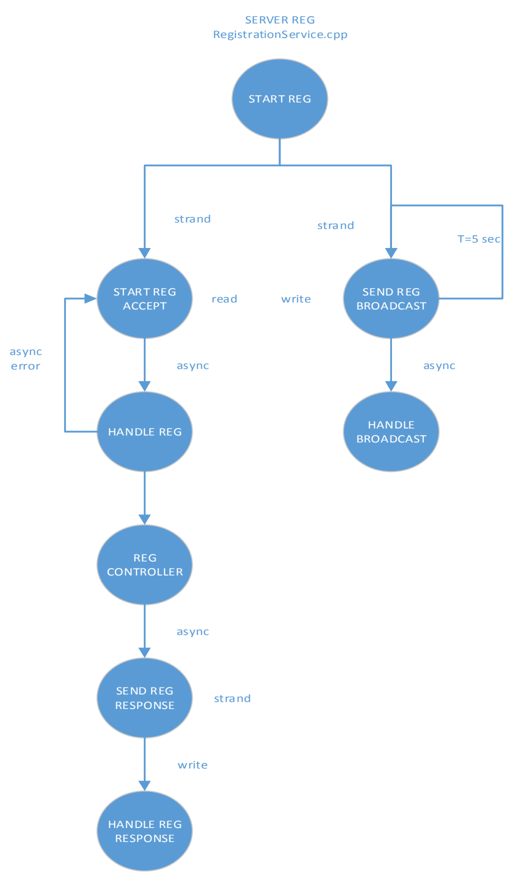


Figure 154: RegistrationService state machine

RouterCommandService

RPCXML stands for Remote Procedure Call Extensible Markup Language. It utilizes XML to encode a HTTP request from a client to a server and vice versa. RPCXML is used for communication between website/mobile reservation system and Master controller. An XML message can be sent across the network with multiple parameters.

The RouterCommandService provides the XMLRPC interface supplied to the web server. This Service requires its own thread to process incoming ticket requests from the thread pool. The XMLRPC interface is implemented using XMLRPC-c, which is an open source project developed in C. The XMLRPC server is single threaded and would not be capable of multi-tasking between many XMLRPC client requests.

Two XMLRPC calls are implemented to handle the reservation requests, “reservation.request”, and “reservation.confirm”. Each procedure returns the same struct in the response. The reservation request begins with a call to the “reservation.request” to inquiry about estimated travel times for the proposed reservation. The estimated time and success of the inquiry is returned in the struct. After the customer confirms their reservation, the “reservation.confirm” is called to begin the process of moving an available pod to pick up the rider.

Below is the sequence diagram that shows the process of requesting a reservation:

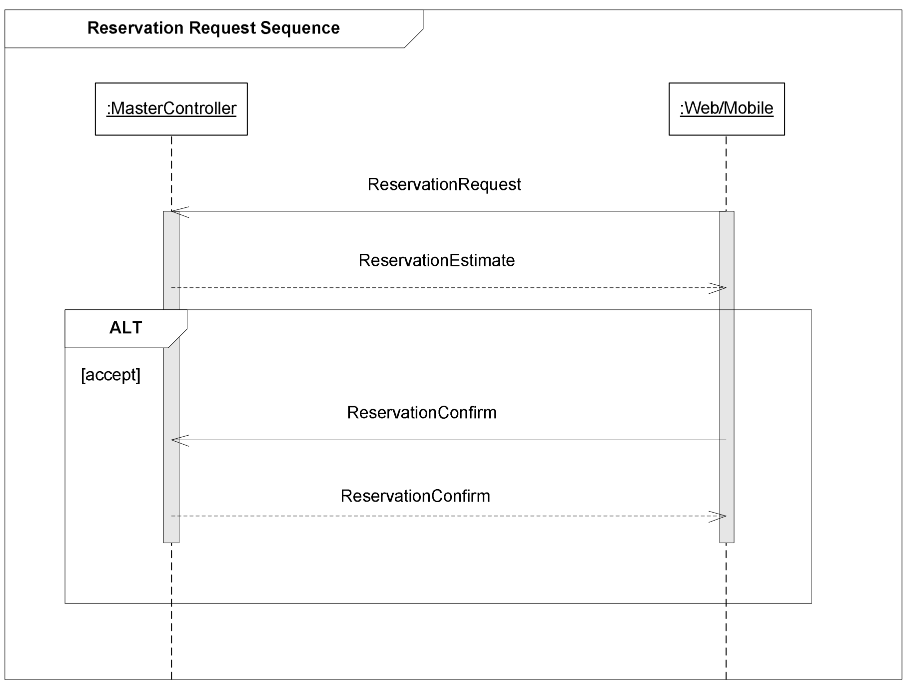


Figure 155: Reservation Request Sequence

The definition of the structure defined in each method is as follows:

Table 25: Returned Structure Format

Name	Type
departure_time	DateTime
arrival_time	DateTime
reservation_expiration	Datetime
origin_id	Integer
destination_id	Integer
success	Bool

Each RPC method is defined as the following:

XMLReservation RequestReservation(int request_id, request_origin, request_destination)

XMLReservation ConfirmReservation(int request_id, bool request_confirm)

All of the above definitions can also be found in the RouterCommandService.h.

All reservations are persisted to the controller database. All reservation IDs sent to the RouterCommandService must be unique across all controller session, or a database key conflict might impact the request.

RouterService
The RouterService is responsible for generating routes for the pod cars across the control system. Any pod routes will be generated through this service whenever a pod is reserved for transportation. The RouterService uses one of the simplest effective approaches available. The graph was weighted using the length of each track segment. The RouterService uses an implementation of Djkstra's Shortest Path algorithm from the Boost library. The Routes are serializable to be easily shared between controllers through the MasterControllerCommService.

Pod Controller
The Pod Controller is a description of the semi-autonomous controller for the pod. Below is a figure of the services used for the controller.

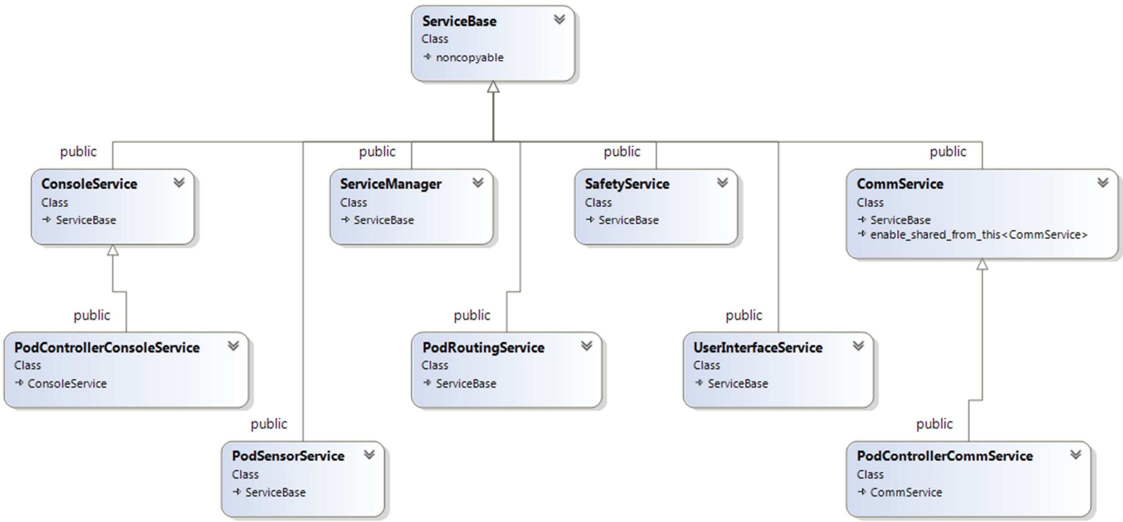


Figure 156: Pod Controller Services and Inheritance

PodControllerCommService

The PodControllerCommService inherits from the SharedServices CommService. It requires registration with the Master Controller and subscribes to the interested services.

PodRoutingService

The PodRoutingService uses the routing directions from the Master Controller received through the CommService. When the Master Controller receives a ticket confirmation, the directions are sent to an available Pod Controller and acted upon by the PodRoutingService. The PodRoutingService has access to a pre-shared map and is capable of keeping position up to date through the SensorService and use hardware to move the Pod along the track.

MergeController

The MergeController was left to the end of the project to save time. Other than the design work in the architectural section, the MergeController, while considered throughout the implementation, did not make it in to the project.

Accessing the Source Code

The project is stored on an SVN repository at http://pod-control-system.googlecode.com/svn/trunk. The control system was made to be cross platform compatible. While most of the development for the code was done under windows, build scripts have been created to support a simplified compilation process under linux using automake.

Getting the libraries

Most of the libraries have been included in the SVN for easy download to the project. The only library that needs to be downloaded, extracted and compiled separately includes Boost. To download the latest Boost library browse to http://www.boost.org. The library must then be extracted using the instructions below.

Windows
To access the code through windows, an SVN repository client, such as TortoiseSVN, must be downloaded. Most of the libraries are included on the SVN and should not need to be recompiled for the Visual Studio Solutions to compile.

1. Navigate to "PRTproject", run "svn check out `http://pod-control-system.googlecode.com/svn/trunk/`"
2. Download the latest Boost library from http://www.boost.org and extract to the libraries folder within the checked out SVN trunk.
3. Rename the boost_(ver) to boost in the libraries folder.
4. Follow the instructions on boost.org for compiling the libraries under windows.
5. Open ControlSystemAll.sln and compile the control system project.

Linux
Pod/Merge Controller will be running on Raspberry Pi operating system (Linux).

1. Make a direction "PRTproject"
2. In terminal, run "apt-get install subversion"
3. Navigate to "PRTproject", run "svn check out `http://pod-control-system.googlecode.com/svn/trunk/`"
4. Download boost library and save it into PRTproject/pod-control-system/libraries/
5. Extract the Boost library to the libraries folder as ./libraries/boost
6. Navigate to "PRTproject/pod-control-system", run " ./build_new" – this should build the entire project, be patient
7. Navigate to "PRTproject/pod-control-system/ControlSystemAll/PodController", run "./PodController" – this will run PodController executable

Next Steps
Most of the messaging framework is implemented; however there is still a significant amount of control system logic that must be implemented.

Testing
The system needs to be well tested. The majority of the semester has been spent on development. While there was some testing performed, only positive test cases were examined within the system.

Shared Services
The CommService could use a more reliable protocol to ensure data does not get lost across the UDP network.

Merge Controller
The Merge controller has not been started on. The Merge Controller can use many of the Shared Services to create a quick implementation. However, logic still needs to be developed for the merge reservation slots.

Pod Controller

The Pod Controller at this time does not have enough logic to make it around the track through the instructions generated by the Master Controller. A state machine must be developed to give the necessary logic to the Pod.

Master Controller

While the Master Controller has had the most development time, it is also the largest controller in the system. Most of the features did make it in to the Master Controller. However, there is still quite a bit of testing that needs to take place to ensure the features work correctly.

Pod Electronics

Central Control and Bus Communications

The pod electronics are an interesting mashup of old and new techniques to create very flexible and debuggable system. A Raspberry Pi embedded computer is engaged as the central control, responsible for communication with the master control (MC) system and coordination of each of the subsystems. Each subsystem is controlled by a special purpose microcontroller (usually from the Microchip 8-bit PIC family), creating a network of intelligent sensors capable of continuing their basic function without input from the Raspberry Pi. Communication between the Raspberry Pi and the various microcontrollers is handled by an 8 bit I/O bus with 8 bit addressing and the common Address Enable, Data Enable, Read, and Write signals. (Rasperry Pi, 2013)

The Raspberry Pi is a small ARM based embeddable system running a customized version of the Linux operating system. With a retail cost of $35 and excellent driver support, the Raspberry Pi provides a stable foundation for the necessary communication for the MC. Utilizing Linux provides a mature TCP/IP stack with excellent software and code support. Further, many cross-platform communications libraries are available, easing the integration of the pod controller software with the MC code base.

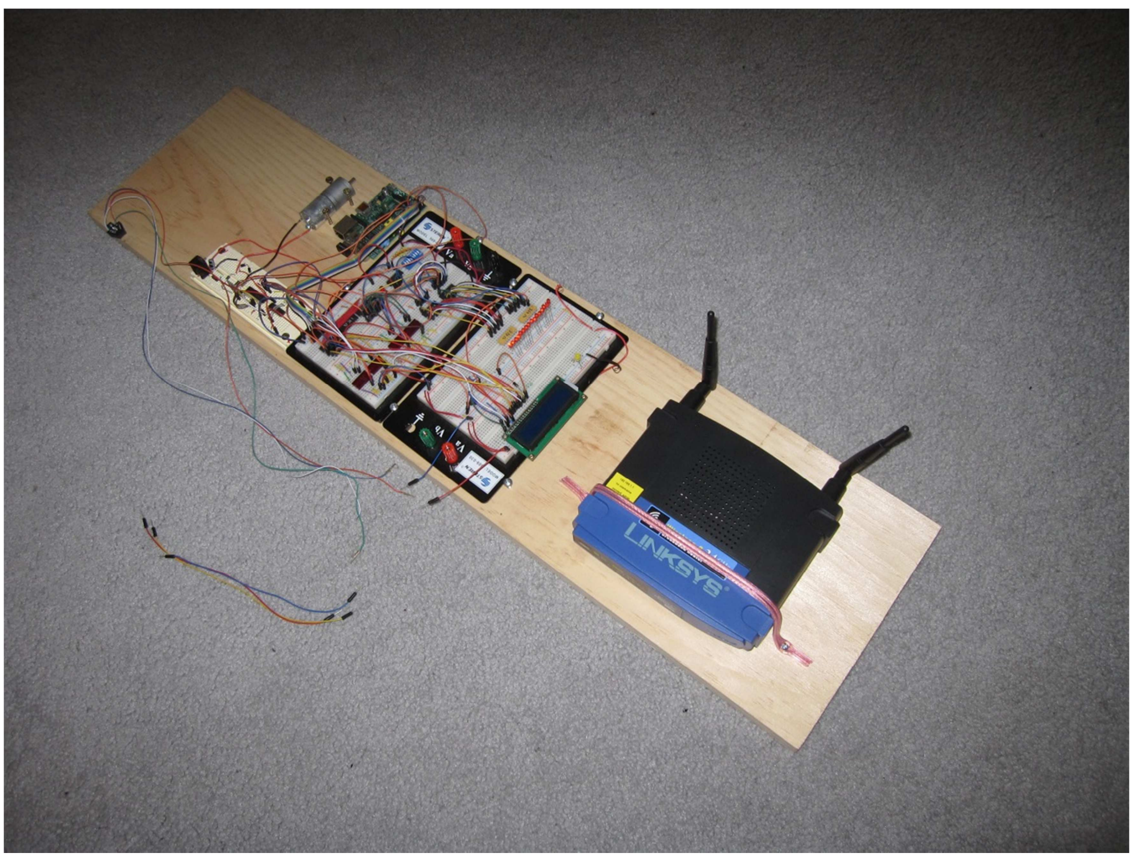


Figure 157: Pod Electronics Prototype Setup

Unfortunately, the Raspberry Pi does have some limitations which must be overcome for a pod controller. The Linux operating system is not a real time system (RTS), and the Raspberry Pi does not have a real time clock (RTC). The absence of an RTS and RTC means there is no guarantee of service for any system operation. In a normal RTS, a delay of 100 microseconds would last for precisely 100 microseconds (within the minimal resolution of the systems RTC, which is usually on the order of nanoseconds). In a general purpose operating system, such as Linux, a usleep(100) system call inserts a delay of *at least* 100 microseconds, with no guaranteed upper bound. Further, the Raspberry PI has a minimal set of general purpose input/output (GPIO) pins. A basic 16x2 liquid crystal display (LCD) requires 10 or more pins to be of use. That one peripheral would use 40% of the Raspberry Pi's available GPIO pins; therefore some additional structure must be put in place to support a larger system.

The Raspberry Pi does support two busses, I^2C and SPI, which are candidates for expanding the number of peripherals which Raspberry Pi could utilize. Unfortunately, the SPI module only supports two chip selects, rendering it unsuitable for all but the smallest systems without significant reworking of the SPI driver. I^2C, on the other hand, with its two wire requirement seems like an ideal solution. Unfortunately, I^2C implementations in the real world are notoriously buggy and frequently do not adhere to the Philips I^2C specification. Without access to a proper I^2C protocol analyzer, the risk of using I^2C for critical systems is crippling.

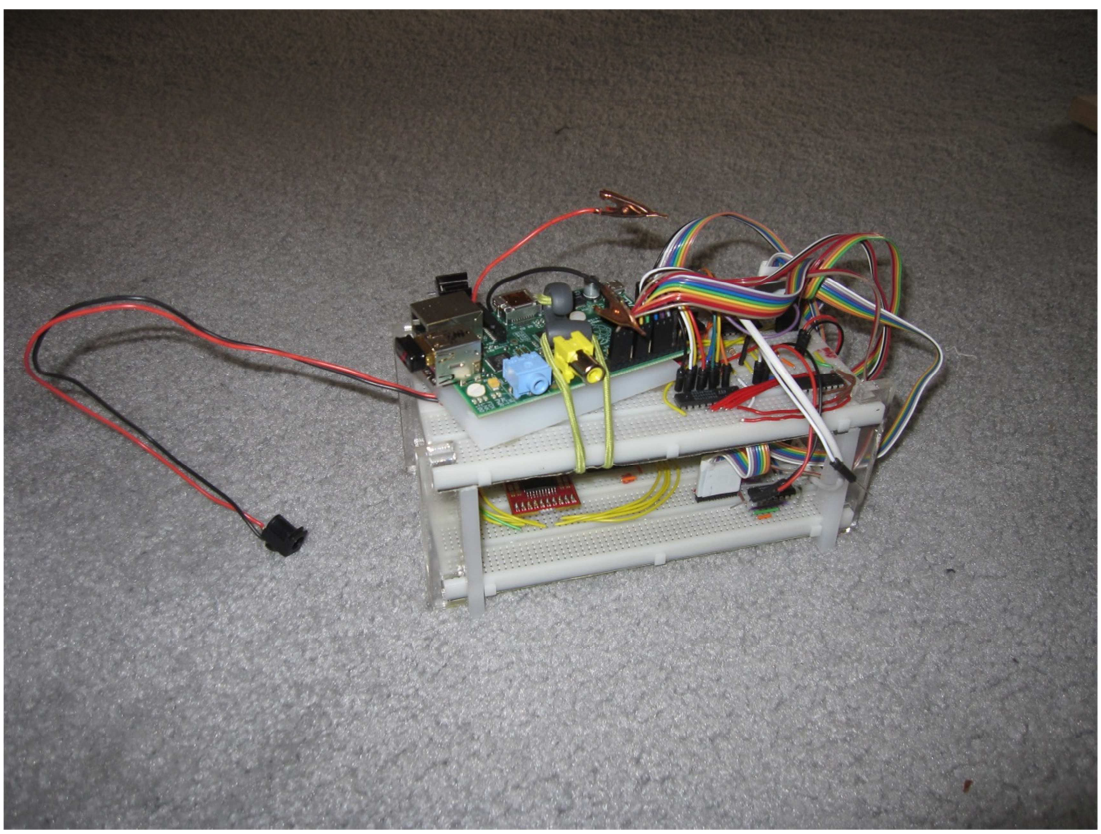


Figure 158: Rev 0.1 in Pod Prototype Electronics

The 8 bit I/O bus is heavily influenced by the I/O bus documented by Intel for the 8088 microprocessor. This approach creates a flexible and extensible system which is debuggable with commonly available lab tools (oscilloscope, logic analyzer, and a logic probe). Further, the initial version of the design integrates bus decoders to show the state of the address and data buses as the system functions (admittedly, these bus decoders really only work for a human when the state of the buses are changing at something less than 10 Hz, but that is commonly sufficient for debug purposes). As implemented, this system can control 16 peripherals, though it is extensible to 64 peripherals without adding additional control signals.

An investigation of the datasheets for the PIC microcontrollers and a perusal of the Raspberry Pi documentation will uncover a seeming incompatibility. The PIC microcontrollers chosen are largely 5V devices compatible with both 5V TTL and CMOS logic thresholds, while the Raspberry Pi is compatible with 3.3V CMOS I/O. This incompatibility is solved by interfacing the Raspberry Pi to its peripherals via appropriately chosen buffers. For output, the 74ACT573 part is utilized. This device can accept 3.3V CMOS inputs and outputs 5.5V TTL levels (5V TTL is sufficient for 5V CMOS in this context). In the other direction, the 74LVX573 has identical logical function to the 74ACT573, though it outputs a 3.3V CMOS level while being tolerant to the 5V CMOS inputs generated by the PIC microcontrollers. Though the 74HCT family could satisfy the needs of the system, as well, the extra switching speed of the ACT parts were desired for this system.

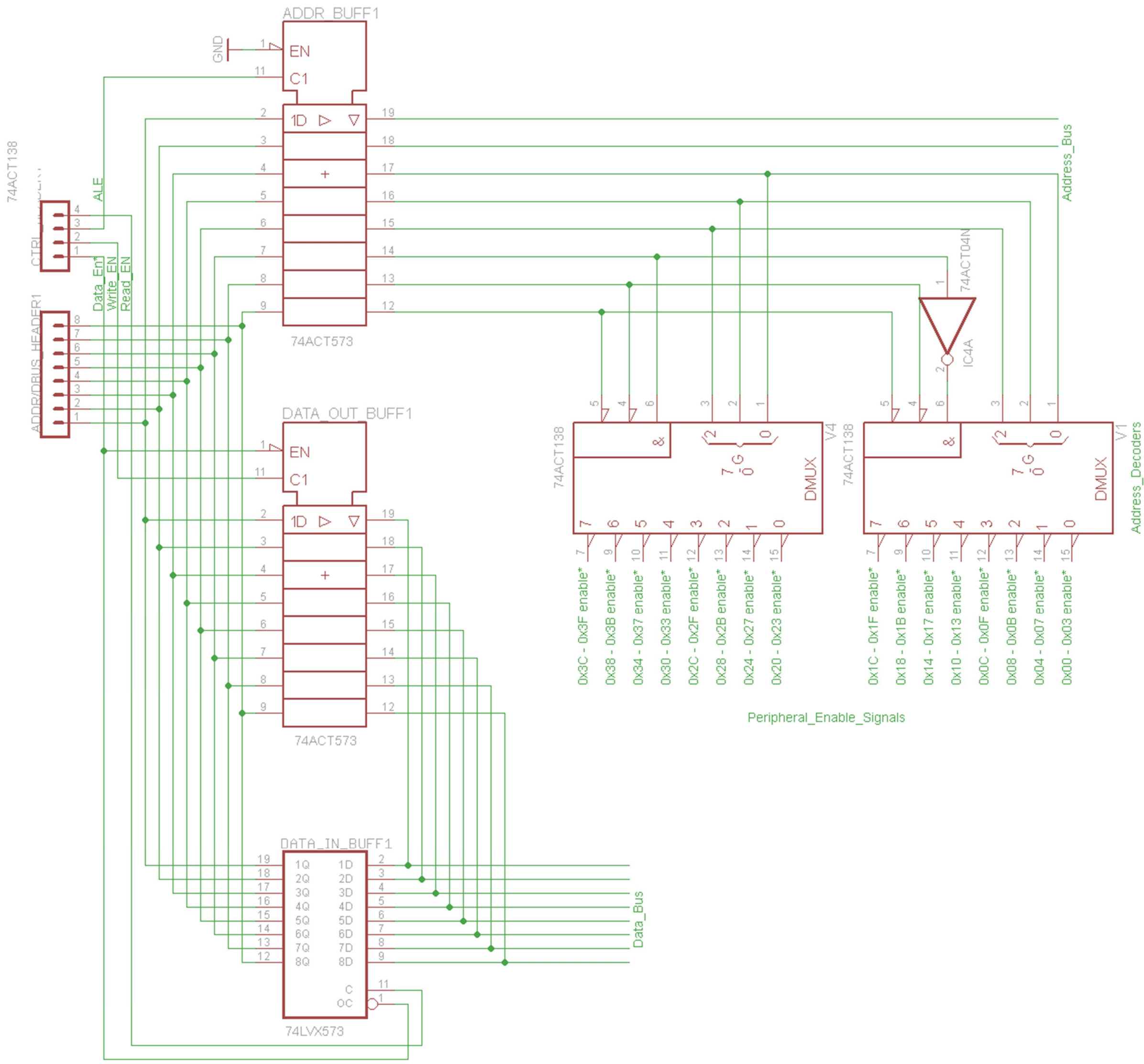


Figure 159: I/O Decoder Circuit

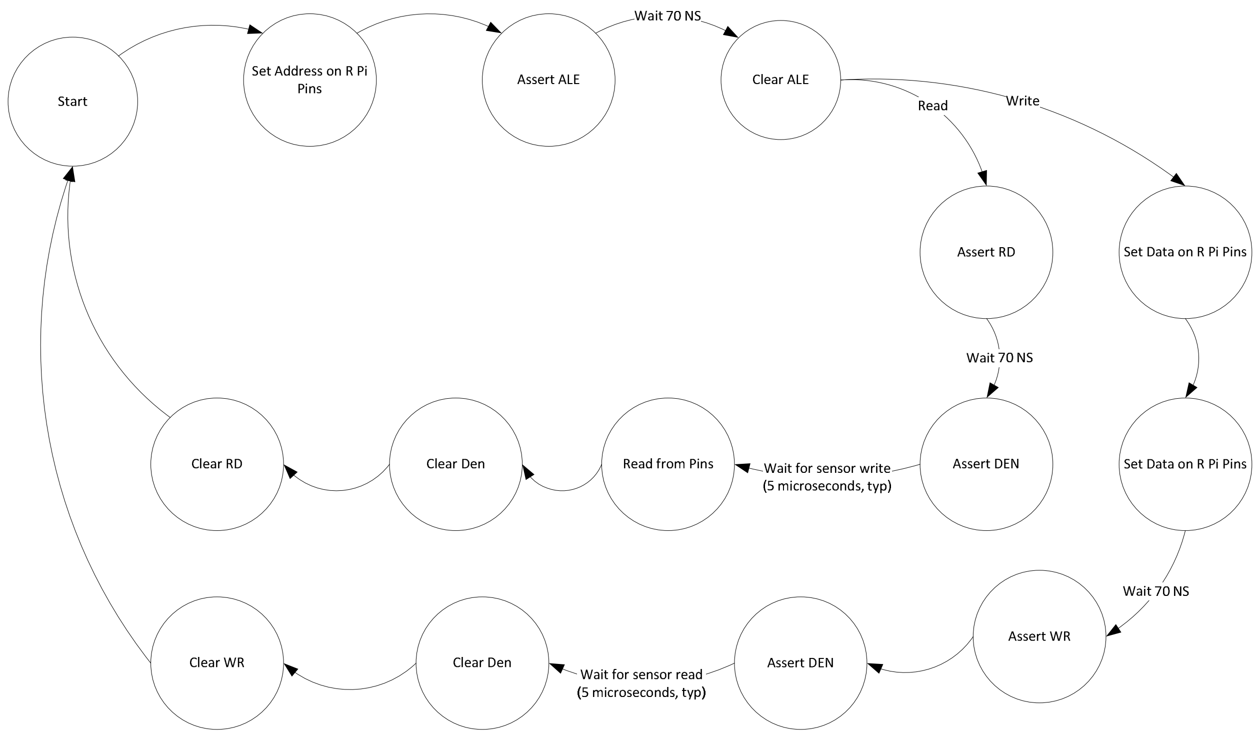


Figure 160: Read/Write Diagram

Peripherals

Motor Control

The drive motor is powered by a pair of 12 V JameCo DC motors. Fortunately, these motors have rather modest current requirements and are drivable from a single solid state quad half-H bridge driver configured as a full H bridge. To allow for future investigation into controlling failure with redundant monitoring circuits, the motors' direction of travel is contained in a discrete latch and the speed of the motor is controlled by a PIC16F627A which feeds a PWM signal into the latch's output enable. When the latch output is disabled, the control lines for the motor are driven low by some very weak pull-down resistors. This arrangement allows for the potential of another system to force the motor to a stop state via additional discrete logic into the direction latch without any action on the part of either the Raspberry Pi or the motor controller.

As should be expected from an H-bridge configuration, a 0x00 control word will stop the motor (since a ground on all control pin would drive both MOSFET gates to ground), while a 0x01 control word drives the motor forward and a 0x02 drives the motor in reverse. In order to obtain the state of the control system visually, a tri-state LED has been connected to unused pins on the latch. In software, a stop control word is actually 0x04, lighting the red LED, 0x09 sends the pod forward, lighting the green LED and 0x12 sends the pod in reverse, lighting the blue LED.

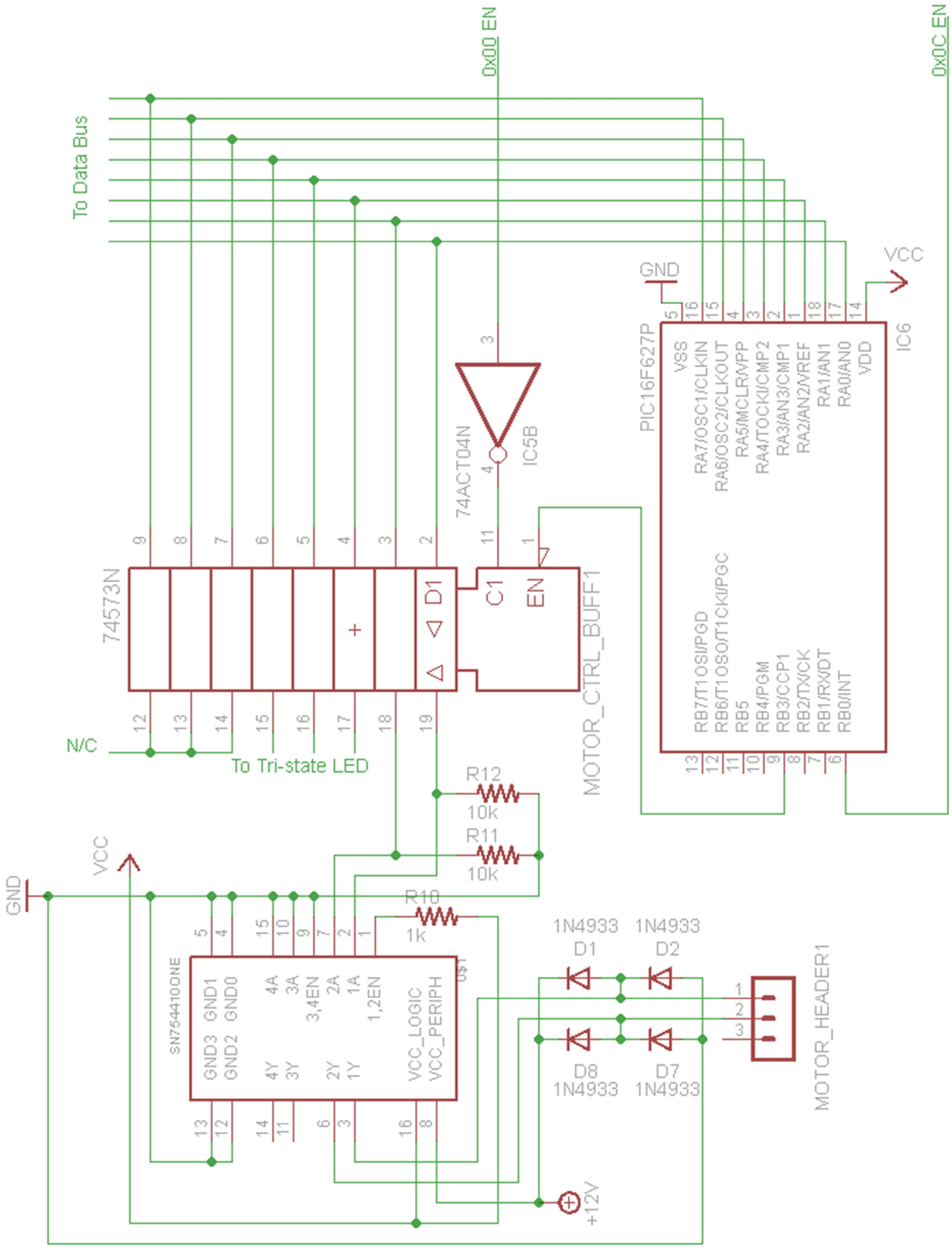


Figure 161: Motor Control Circuit

Steering

Though the current system only requires a binary Left or Right steering control, the bogey is designed with a 180 degree servo electric motor. It is possible for some future system to have a more complex junction. To support this possibility, a control circuit has been designed with four degree resolution. A 0x01 control word corresponds to full Left and a 0x29 control word corresponds to full Right. In between values choose somewhere between the two extremes at the mentioned four degree increment. Casual inspection shows that these control words have a maximal bit width of 6 bits. The microcontroller masks off the upper bits to avoid over-driving the servo beyond its functional range.

Implemented in a PIC16F627A, the steering control circuit is not horribly interesting, yet provided for completeness.

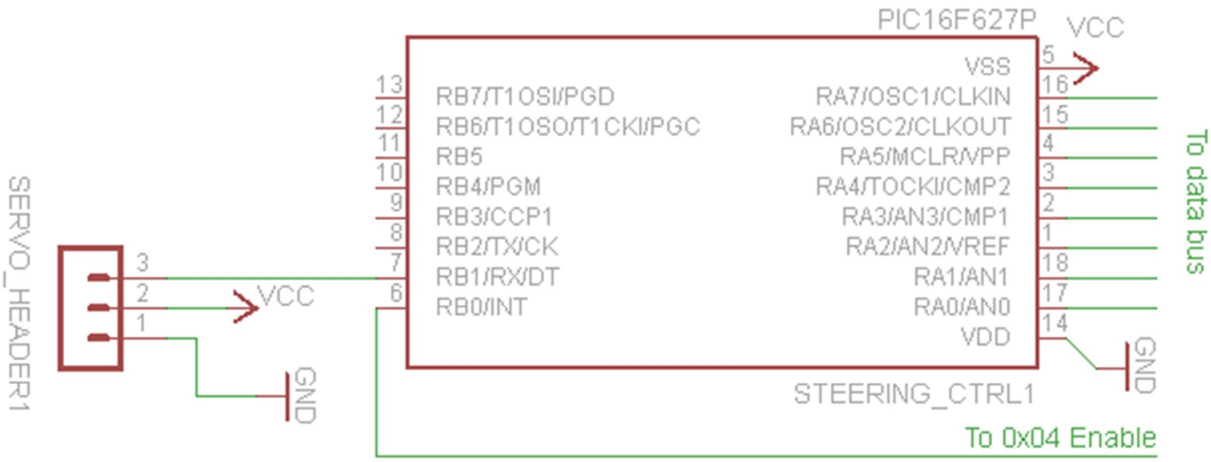


Figure 162: Steering Control Circuit

Position Identification

The track will be split up into 9" segments, bounded by reflective aluminum tape. The pod will have three optical sensors capable of detecting these reflective strips, allowing the pod to communicate its location to the MC with acceptable resolution. A 9 inch resolution for this system makes sense, given the pod length. Since absolute position on the track is the most critical, redundant sensors are used to ensure reasonable agreement on location.

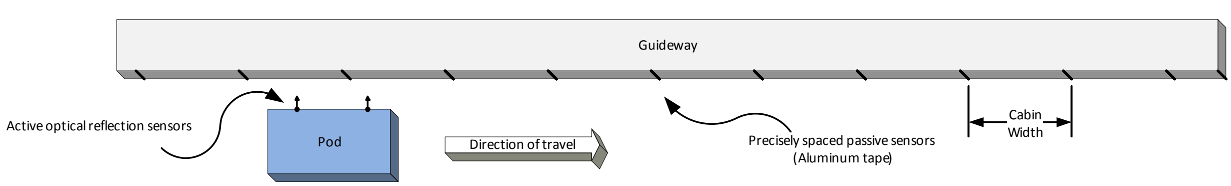


Figure 163: Position Determination

Each position sensor has a dedicated PIC16F690 microcontroller with built-in analog to digital conversion (ADC) circuitry. The ADC in the PIC16F690 has a 7 microsecond conversion time, which is more than quick enough for this system's needs.

The OPB703 sensor used has an optimal focal distance of ¼” with a reasonable functioning range of 1/10” to ½”. This focal length defines the maximal deviation in the distance between the top of the pod and the track.

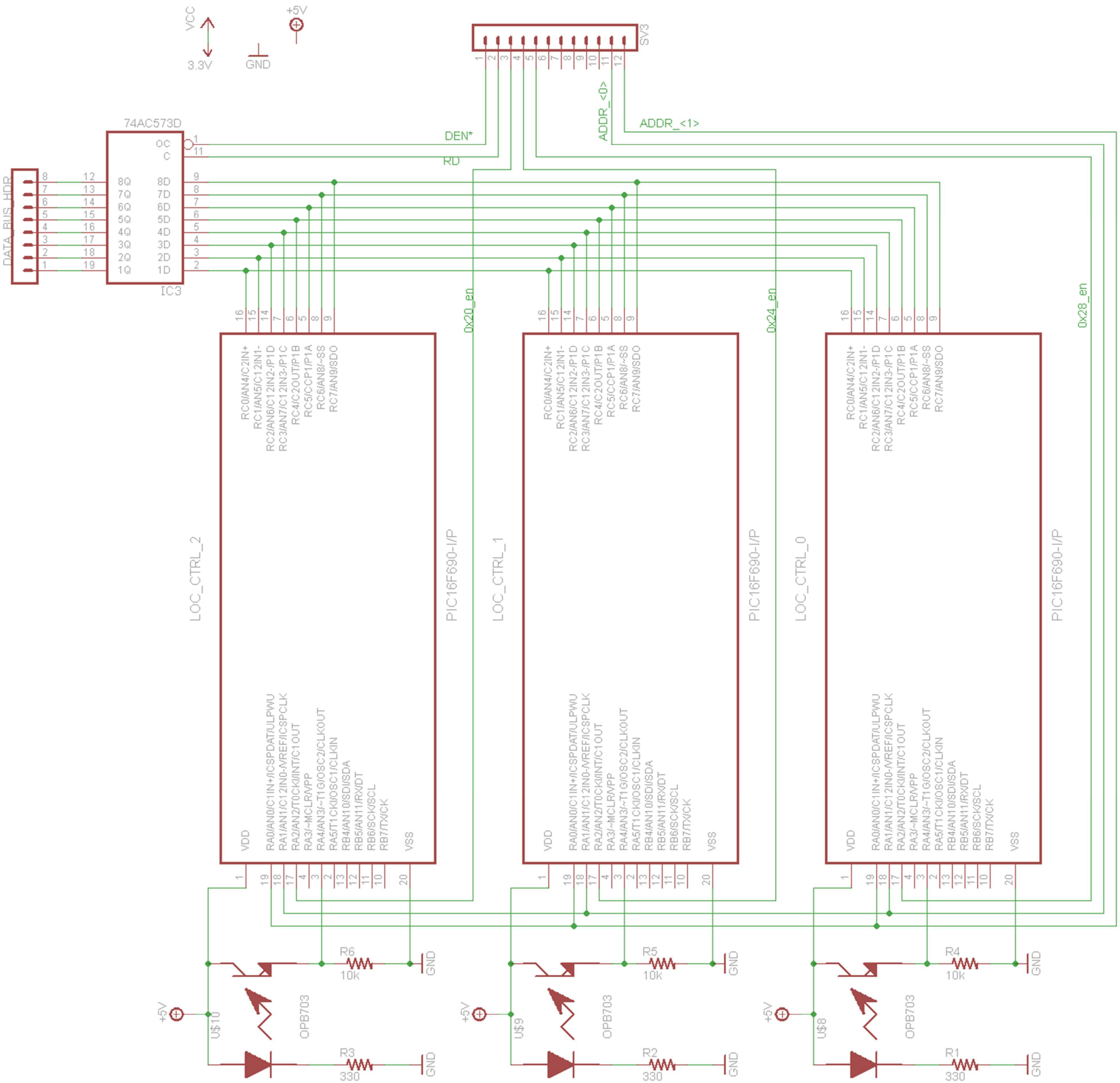


Figure 164: Position Sensing Circuit

Though this system has been proven off of the track, it is still to be implemented on the track.

Next Steps

There is still much to be implemented in the controls and electronics:

Near Term:

1. To fit all designed peripherals into the pod, circuit boards must be printed. At current, there is insufficient space for the planned collision sensors, the LCD display giving status, and more than one of the position sensors.
2. The positioning needs to be integrated into the rail. For this to occur, the bogey to pod link must be completed and brought to within specification
3. Two additional pods must be brought online to allow the MC and merge controllers to be properly tested
4. Internal environmental control (temperature and humidity) should be implemented along with some type of active cooling (most likely a fan controlled by the motor control circuit). The inside of the pod is getting warm with this subset of the electronics. Once the power distribution is completed, the heat will increase.

Longer term:

1. The entire bus system is big a bit complex. A CPLD, FPGA, or a slave microcontroller should be investigated as a replacement. It is possible such a system would be less energy intensive, simpler, and more fault tolerant
2. Fault tolerance throughout the system should be implemented. Currently, there are many single points of failure. Adding redundancy will allow this model to more closely approximate a system meeting real-world requirements.
3. Moving to a more real-time operating system will allow the entire pod control to be more deterministic. There are real-time enhancements to Linux which could be explored. Alternatively, there are many real-time operating systems available for the embedded space. One or more of these may have sufficient communications capabilities to be a reasonable Linux alternative.

Chapter 12: Conclusions and Next Steps

Cabin

The main goals and objectives for this semester were to meet the federal safety regulations and Americans with Disabilities Act requirements and select basic materials for manufacture. By using the available information on other personal rapid transport systems throughout the world, the design developed sought to encompass any advantages that these systems have as well as address weaknesses and account for them in the model presented.

One distinct disadvantage of this system and major obstacle that will be faced is to prove that a suspended system can be as reliable as an override system. To overcome this obstacle, it will be imperative to assure the public that if the system is put into operation that the cabin will not detach from the guideway by doing various analyses to test the strength of the exterior and ensure sufficient attachment to the guideway.

These critical next steps will involve full stress analysis on cabin exterior, which includes a finite element analysis to test the attachments between the bogey and the cabin as well as any tension stresses resulting from the suspended guideway to test for the possibility of crack propagation in the body near bolts, and well as tear out stresses resulting from shear stresses on the bolts.

In addition, the aerodynamics of the pod shape itself needs to be tested as drag on the cabin will be a key component while the cabin travels in the system and is especially critical since the system will be suspended. This process will require help from the Aerospace department to test the plastic 3-D prototype in the wind tunnel.

We will also need to research and test various ergonomic aspects of the cabin, including seat height, grab bar placement, and any other device that relates to human interaction. Without proper ergonomics, passengers will not be able to enjoy the safety and comfort of the cabin.

The results of these various tests and analyses will be used to optimize the final pod shape and materials in the following semester.

Propulsion

Various propulsion types were considered to propel the pod car. The selection of the propulsion system type was based on the propulsion team's analysis of previously established systems. It was decided that a linear induction motor (LIM) will be responsible for the propulsion of the SuperWay system. LIM's offer the advantage of few moving parts, which leads to less maintenance and lower noise levels, reliable thrust in all weather conditions, and the linear motor can be placed in the track to allow for a lighter cabin. The bogie is designed for durability, comfort, and performance.

Next steps for the project are:

- A finite element analysis (FEA) is needed to optimize the bogie for strength and durability. Stress analysis is needed on all components of the bogie and its contact points within the guideway channel.
- Thorough analysis (vibrations and control) of the suspension system including simulations and calculations to verify that it will be able to provide a smooth and safe ride.
- Incorporate the linear induction motor, the bogie and guideway design as a whole. This includes CAD models and kinematic simulations.

Structure

The next steps in the design of the structures/guideway system include calculating cost, forces, and the overall adequacy of the system. In addition, a meticulously analysis will be conducted to find the period and natural frequency of vibration of the structure to prevent its failure during an earthquake event or due to the loading provided by high wind speeds. The guideway truss will also be analyzed in more detail to assure that it doesn't deflect more than the allowable. In addition, the cross-sectional area of the elements of the truss has to be analyzed for fracture and yielding. A certain type of material will have to be designed to cover the truss and prevent it from weathering out. Moreover, the piles at the foundation will have to be analyzed for earthquake resistance economic feasibility.

Station

This main focus of this semester revolved around addressing the varying volumes of traffic to which individual stations might be exposed as well as possible methods of storage. Using knowledge of the systems that current public transportation use and tailoring and modifying them to needs posed by the corridors that will be identified later in this report.

The next steps for station design include designing the actual architecture for the building, both interior and exterior. Another crucial step is designing the layout of the building itself as to where ticketing kiosks, restrooms, platforms and other aspects of that nature will be placed, as well as user interaction with the system at the station. This will require students or experts with architecture, civil engineering, and industrial design backgrounds.

In addition, next semester will also require more analysis surrounding traffic flow, pod throughput, and optimizing station design to ensure that the storage of empty vehicles can meet system demands. This effort should be managed by those with a background in industrial systems design.

Solar

The Solar SuperTeam designed a solar power system that will meet the energy requirements of an ATN. Commercial available solar cell technology with high efficiency is the ideal choice to maximize energy production in San José, CA. Designing the solar panels to blend in with the overall structure of the guide way increases the visual appeal and is good thermal management.

The next steps for the solar team

- Finalize the design for the frame structure for the solar panels and its integration with the guide way columns.
- FEA analysis on solar frame structure concerning maximum wind loads.
- Economic analysis as a hybrid grid-solar powered system.

Control Systems

The technological overview for the control system is limited to an examination of high level architecture. Redundancy is a primary goal of the overall system and thus will use a combination of redundant functionality integrated into the software architecture, and additional hardware in case of hardware failure. Many aspects of the technological implementation still need to be explored before specific hardware and technology can be discussed.

Communication Medium

Communication between controllers will need to be accomplished through redundant mediums. Wireless technology is the easiest to maintain, however suffers from interference from the environment and therefore too unreliable for the only communication medium.

A second medium may be implemented into the guideway power line. While the communication would be more susceptible to large collision damage, a reliable slow rate medium can be used in cases of wireless failing.

Additional research is still needed to understand the data rate requirements of the system before a decision can be made.

Master Controller

The technological implementation of the Master Controller would use multiple hardware platforms with state awareness for high availability. The backup platforms would maintain the same state as the primary Master Controller for minimal downtime during hardware failure. Any required database access would be shared between the system using raid enabled storage area network (SAN) technology for the quickest and highest reliability. In the case of the primary Master Controller failing, the system would immediately failover to a backup Master Controller and resume normal operation.

Merge System

The Merge System will incorporate many sensors to detect positions of pods on the guideway. The sensors will need to be durable and reliable. At this time no technological options have been chosen for this system.

Autonomous Pod

Pod Controller will have multiple sensors for hardware failure detection, hardware malfunction detection, keep pod running on guideway, blockage, etc. Communicating devices must provide high availability and reliability for the system. The user interface should also be implemented on the pod to provide communication between users and Master Controller administrators.

Reservation System

The Reservation System will be implemented through a Web Browser Side component and a Server Side Component. The Web Browser side component serves as the interface for the user and admin to communicate with the server and database. For this system, a web server will be implemented to transfer information between the customer and an Sequential Query Language (SQL) database.

The architecture chosen for the control system looks like a viable option for implementation. Not only is the system highly scalable, but it provides fault tolerance throughout the system. Even in the event of the primary Master Controller failing, the system is capable of providing limited functionality to bring passengers to safety. However, the system remains far from complete and still has many facets to be tackled before a complete solution can be envisioned.

In the future, additional refactoring will need to take place as more analysis is done on the system fault tolerance. Additional work must be done to ensure no single point of failure would devastate safety critical components.

Other areas that need to be inspected include the technologies used to implement communication, and the variety of sensors used in the pod, track, and in the merge intersections.

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Appendix A: Derate Factors used in SAM Simulations

The default derate factors in SAM are used for the simulation to predict the energy output in San Jose, CA. Figure 165 shows the values used.

Figure 165: SAM system derate factors used for simulation

Module	**Module Efficiency %**	**Net Annual Energy (kWh)**	**Energy Output per Mile (kWh/mile)**	**Energy Available for Grid (kWh/mile)**	**Total Modules Required for Energy Output per Mile**	**Average Daily DC Power (kWh)**	**Average Daily Energy (kWh)**	**Maximum Energy (kWh), July**
SunPower: SPR-440 NE-WHT-D Mono-c-Si	21.3	972,745	3,778	1,334	1,609	2,920	2665.05	105,117
	Total Modules for Desired Array Size	**Total Module Area (m²)**	**Module Length (m)**	**Module Width (m)**	**Module Weight (kg)**	**Total Land/Space Area (m²)**	**Packing Factor**	**Space Between Panels (m)** ***Module Width is Parallel to Guideway***
	1,135	2346.05	2.067	1	25	2815.254	1.2	0.2
	Setup	**Tilt (°)**	**Azimuth (°)**	**Inverter**	**Number of Inverters**	**90% Power Output Warranty Period (year)**	**@ Optimal Tilt Angle Using 500 kW DC as the Desired Array Size**	
	Fixed	32	180	SMA America: SWR2500U 240V [CEC 2005]	200	10		

Appendix B: SAM Simulation for SunPower SPR 440 Module

Table 26 shows the parameters used to run the simulation to determine the total energy output of the solar PV system for the SuperWay. In addition, Table 26 shows the results from the simulation and the calculated energy output per mile. The energy output per mile was calculated based on the average energy output per module. Assuming that the modules would be aligned right next to each other with a packing factor of 1.2 for a distance of one mile and that the modules would be aligned in the width direction (1 meter in length), we determined the amount of modules per mile, and thus, the energy output per mile.

Module	Module Efficiency %	Net Annual Energy (kWh)	Energy Output per Mile (kWh/mile)	Energy Available for Grid (kWh/mile)	Total Modules Required for Energy Output per Mile	Average Daily DC Power (kWh)	Average Daily Energy (kWh)	Maximum Energy (kWh), July
SunPower: SPR-440 NE-WHT-D Mono-c-	21.3	972,745	3,778	1,334	1,609	2,920	2665.05	105,117

Table 26: Parameters and results from SAM simulation

Si								
	Total Modules for Desired Array Size	**Total Module Area (m²)**	**Module Length (m)**	**Module Width (m)**	**Module Weight (kg)**	**Total Land/Space Area (m²)**	**Packing Factor**	**Space Between Panels (m)** ***Module Width is Parallel to Guideway***
	1,135	2346.05	2.067	1	25	2815.254	1.2	0.2
	Setup	**Tilt (°)**	**Azimuth (°)**	**Inverter**	**Number of Inverters**	**90% Power Output Warranty Period (year)**	**@ Optimal Tilt Angle Using 500 kW DC as the Desired Array Size**	
	Fixed	32	180	SMA America: SWR2500U 240V [CEC 2005]	200	10		

Appendix C: SoloPower SFX1-i Specifications

For testing purposes, the SoloPower SFX-i specifications are provided below.

SOLOPOWER® SFX1-I SPECIFICATIONS

Dimensions 0.292m x 3.05m
Power Ranges 65-75 Wp

APPLICATIONS

Segments: Commercial, Industrial, and Residential Rooftops

ELECTRICAL CHARACTERISTICS (STC)[1]

SoloPanel SFX1-I		I65	I70	I75
Rated Power (Pmax)[2]	W	65	70	75
Voltage at Pmax (Vmp)	V	20	21	22
Current at Pmax (Imp)	A	3.3	3.3	3.3
Short-circuit current (Isc)	A	4.0	4.0	4.0
Open-circuit Voltage (Voc)	V	29	30	32
Efficiency[3]	%	8.8	9.5	10.1

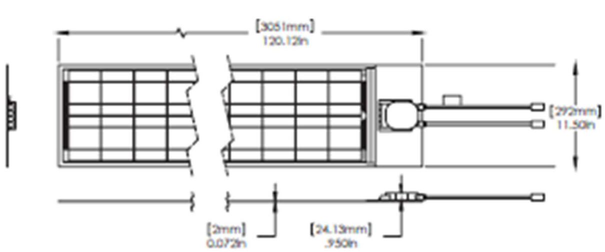
1. STC standard test conditions: 1000W/m² intensity, Air Mass 1.5, 25°C cell temperature. The power tolerance is -3% / +5% Wp, at STC. The electrical characteristics are within ± 10% unless otherwise specified.
2. Stabilized Power.
3. Aperture Efficiency.

Solopower SFX1-I					
Temp. Co-efficient of Isc	%/°C	+ 0.002			
Temp. Co-efficient of Voc	%/°C	- 0.35			
Max. Series Fuse Rating	A	5	VDC	600	ATM Type
Maximum DC Voltage					
US	VDC	600			
EU	VDC	1,000			
NOCT	°C	50			

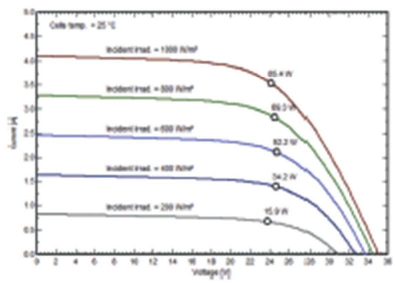
PHYSICAL CHARACTERISTICS

Solopower SFX1-I	
Length	120.1 in / 3.05 m
Width	11.5 in / 0.292 m
Thickness	0.1 in / 2.0 mm
Weight	5.0 lbs / 2.27 kg
Roof Load From Module	0.53 lbs/ft² / 2.61 kg/m²

MECHANICAL DRAWING



IV CURVES



Current (A) vs. Voltage (V) at various Irradiance levels

QUALIFICATIONS

Certified to Standards: UL 1703, IEC 61646, & IEC 61730.

WARRANTY

Limited Warranty

Materials and/or workmanship: 5 years

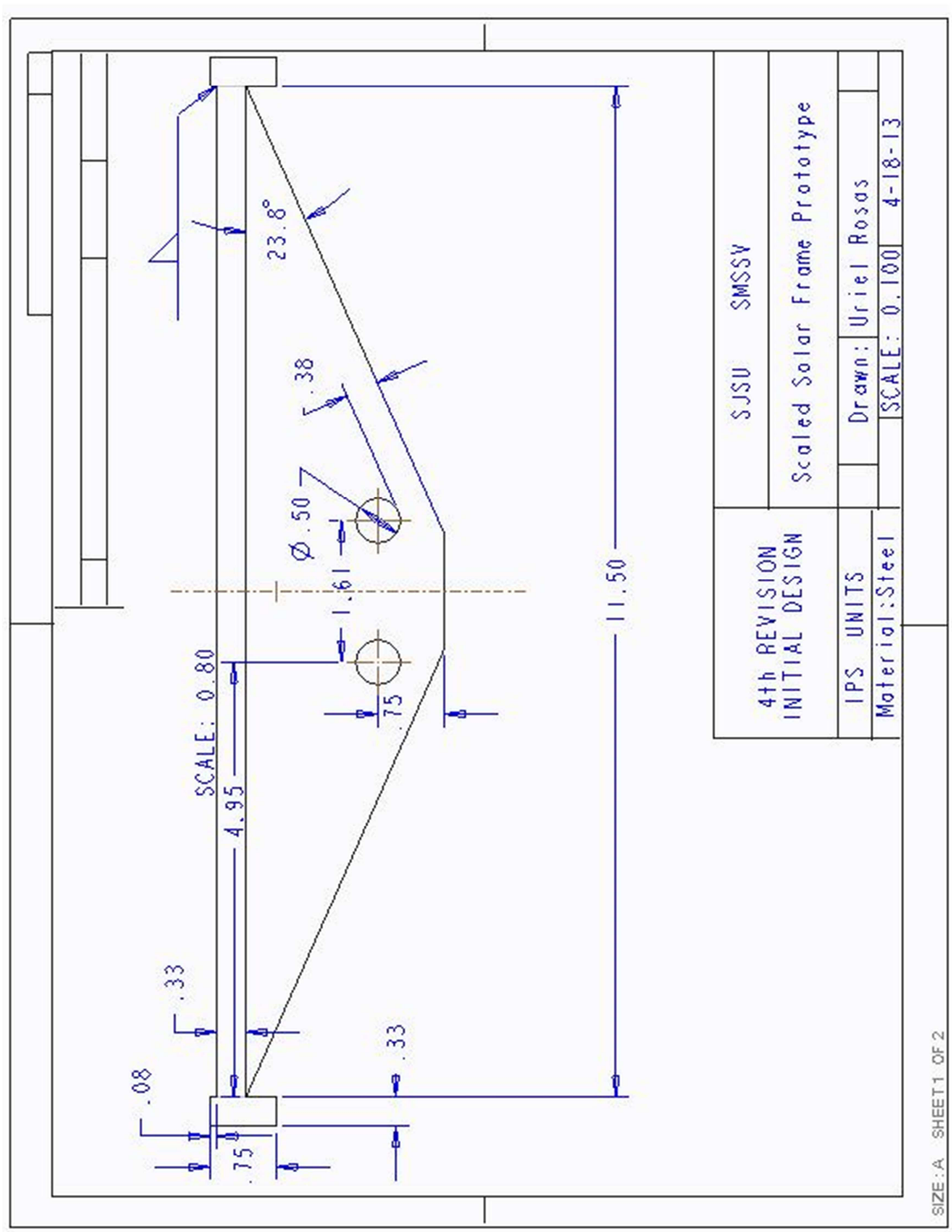
Power output: 25 years (90% of nominal rated power for years 1 to 10, 80% of nominal rated power for years 11 to 25). Designed and manufactured in the US.

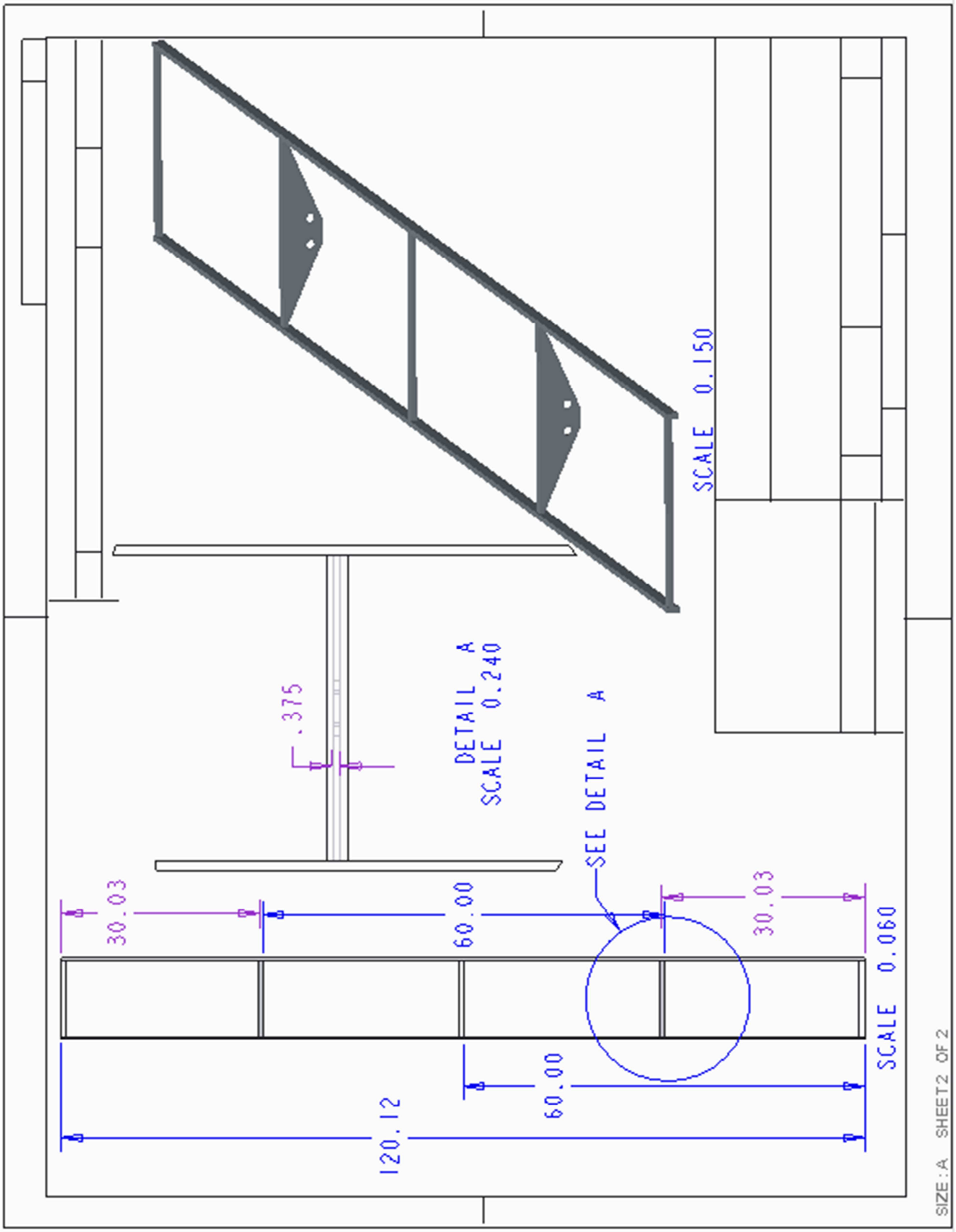
Contact sales@solopower.com for complete terms of the limited warranty.

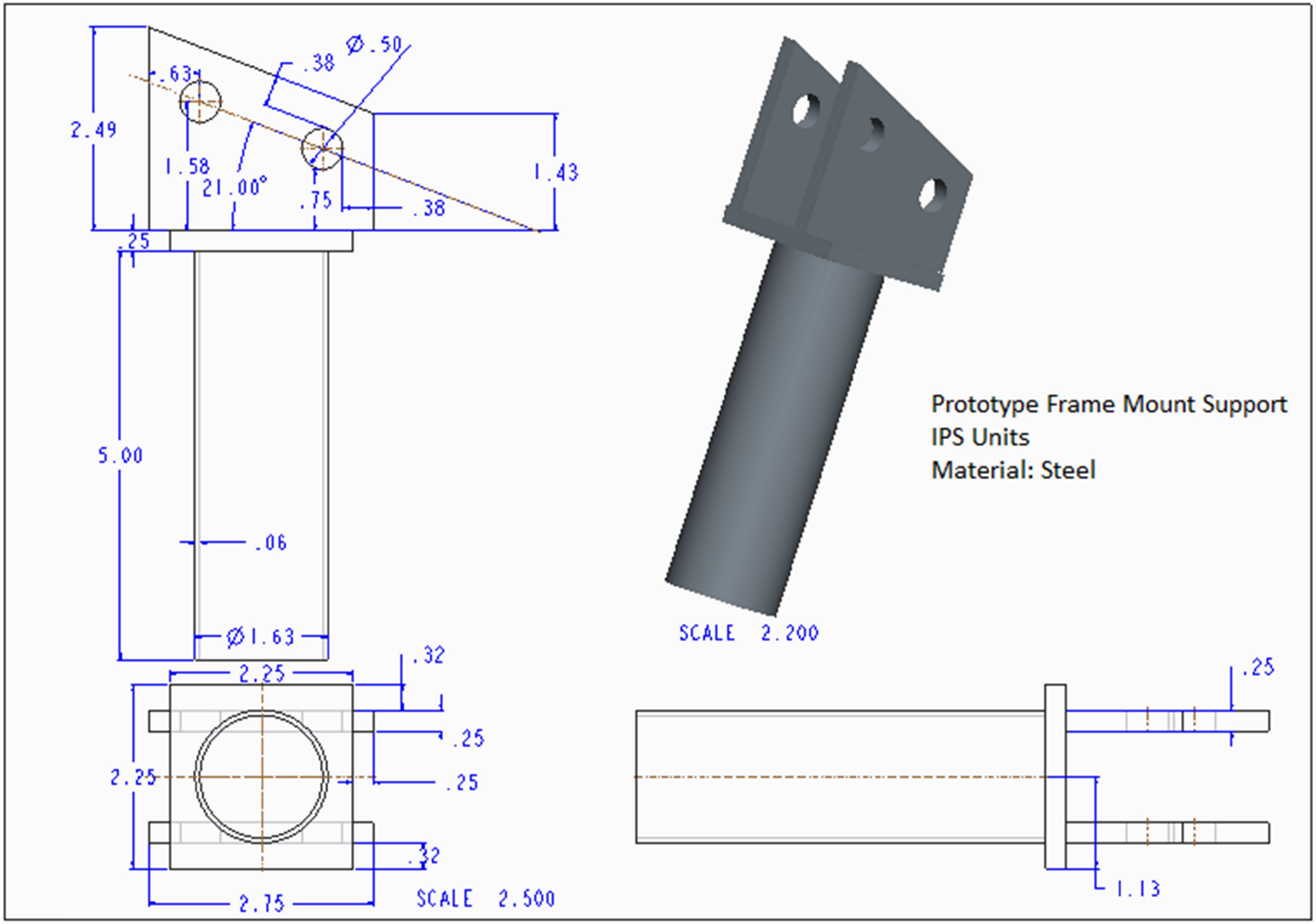
SOLOPOWER
San Jose, CA USA
www.solopower.com

Product Specifications Sheet SoloPanel® Model SFX1-I

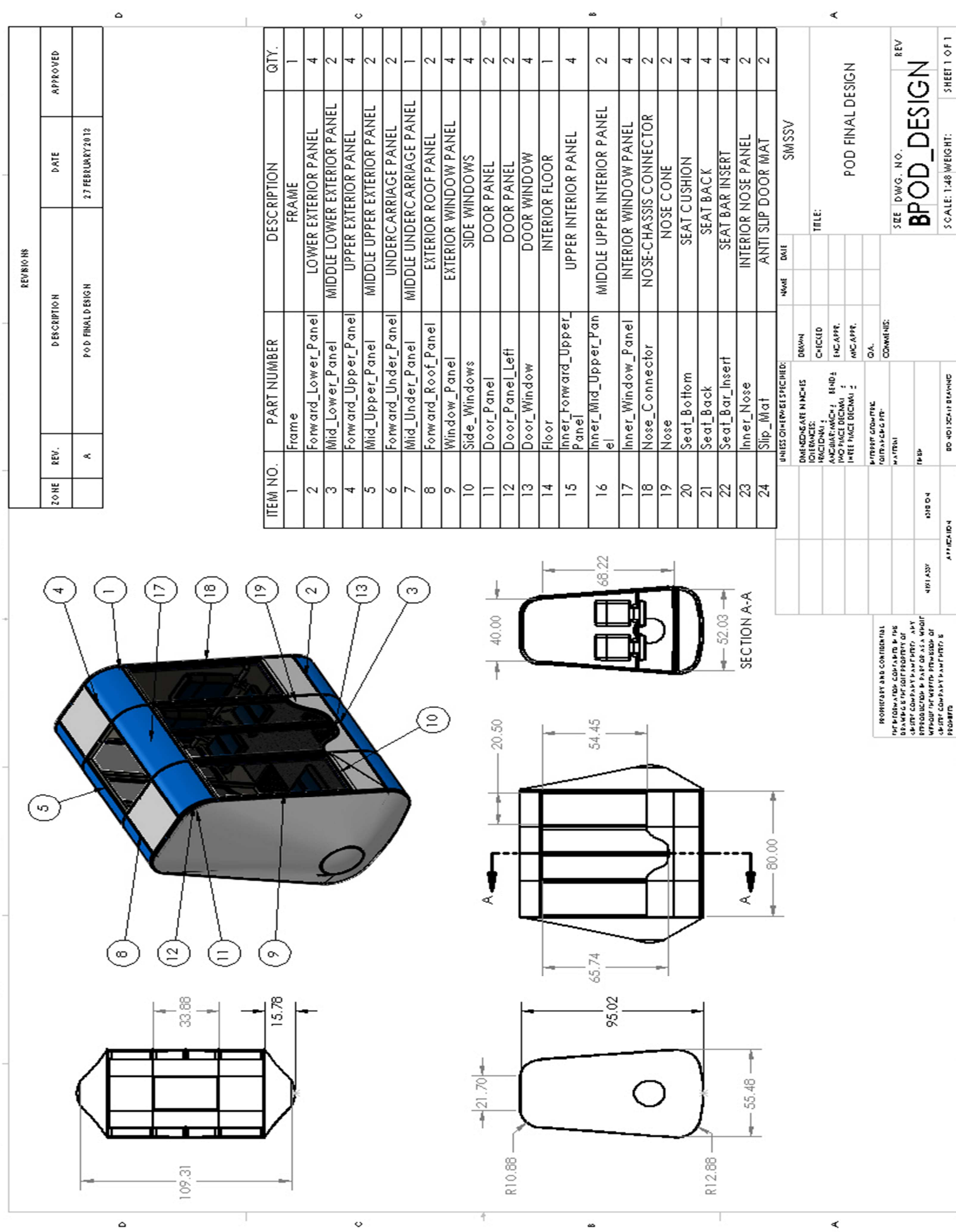
Appendix D: Prototype Solar Support Structure Drawings




SCALE 0.150
DETAIL A
SCALE 0.240
.375
SEE DETAIL A
30.03
60.00
30.03
SCALE 0.060
60.00
120.12
SIZE : A SHEET 2 OF 2

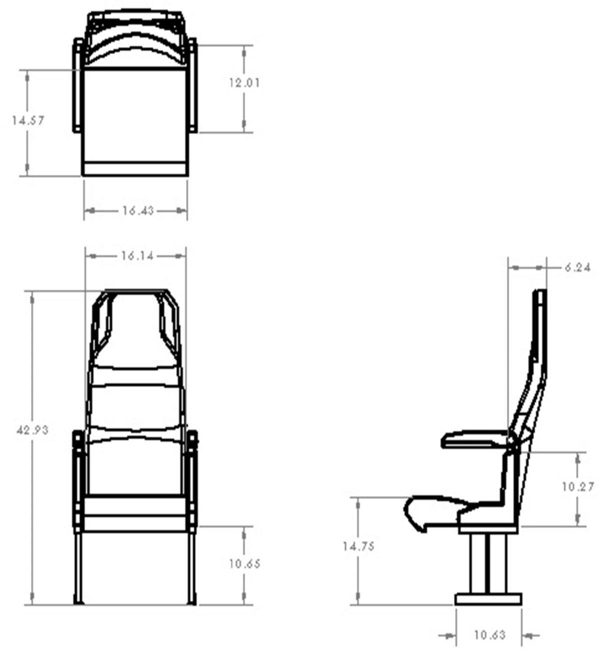

Prototype Frame Mount Support
IPS Units
Material: Steel
SCALE 2.200
SCALE 2.500
Ø.50
.38
.63
2.49
1.58
21.00°
.75
.38
1.43
.25
5.00
.06
Ø1.63
.32
2.25
.25
.25
2.25
.32
2.75
.25
1.13

Appendix E: CAD Drawings of Cabin



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Frame	FRAME	1
2	Forward_Lower_Panel	LOWER EXTERIOR PANEL	4
3	Mid_Lower_Panel	MIDDLE LOWER EXTERIOR PANEL	2
4	Forward_Upper_Panel	UPPER EXTERIOR PANEL	4
5	Mid_Upper_Panel	MIDDLE UPPER EXTERIOR PANEL	2
6	Forward_Under_Panel	UNDERCARRIAGE PANEL	2
7	Mid_Under_Panel	MIDDLE UNDERCARRIAGE PANEL	1
8	Forward_Roof_Panel	EXTERIOR ROOF PANEL	2
9	Window_Panel	EXTERIOR WINDOW PANEL	4
10	Side_Windows	SIDE WINDOWS	4
11	Door_Panel	DOOR PANEL	2
12	Door_Panel_Left	DOOR PANEL	2
13	Door_Window	DOOR WINDOW	4
14	Floor	INTERIOR FLOOR	1
15	Inner_Forward_Upper_Panel	UPPER INTERIOR PANEL	4
16	Inner_Mid_Upper_Panel	MIDDLE UPPER INTERIOR PANEL	2
17	Inner_Window_Panel	INTERIOR WINDOW PANEL	4
18	Nose_Connector	NOSE-CHASSIS CONNECTOR	2
19	Nose	NOSE CONE	2
20	Seat_Bottom	SEAT CUSHION	4
21	Seat_Back	SEAT BACK	4
22	Seat_Bar_Insert	SEAT BAR INSERT	4
23	Inner_Nose	INTERIOR NOSE PANEL	2
24	Slip_Mat	ANTI SLIP DOOR MAT	2

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED
	2	SECOND REVISION OF SEAT DESIGN (SPRING LOADED)	10 MARCH 2015	



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	SEATBACK_FRAME	SEAT BACK AND FRAME	1
2	SEAT_BOTTOM	SEAT BOTTOM & CUSHION	1
3	ARMREST	ARMRESTS	2
4	SUPPORTS	SEAT SUPPORTS	2

SMSSV

TITLE:

SEAT DESIGN

SIZE B | DWG. NO. SEAT_REV_B | REV

SCALE: 1:16 | WEIGHT: | SHEET 1 OF 1

Appendix F: Seat Spring Calculations

To begin calculations for the seat springs, it is assumed that unpeened music wire (ASTM 228) of wire diameter *d* of 0.192 in. and a spring index of *C*=9. Through the iterative process in an Excel spreadsheet, it was determined that we needed an 8 in. end length so for the purposes of calculations shown here, those results will be shown. Also since the two springs are identical, calculations are shown for one spring with half of the assumed required load.

The mean coil diameter *D* is calculated using the following equation.

$$D = Cd = 9(0.192\ in) = 1.728\ in$$

The inner and outer coil diameters, D_i and D_o, respectfully are calculated in the following way:

$$D_i = D - d = 1.728\ in. - 0.192\ in. = 1.536\ in$$

$$D_o = D + d = 1.728\ in. + 0.192\ in. = 1.920\ in$$

It is assumed that the force required to push down the seat is 10-15 lbf, therefore the minimum and maximum weight loads for one spring is 5 and 7.5, respectively. Since torsion springs are loaded in torsion, the maximum and minimum moments, M_{max} and M_{min} must be calculated as shown by the following equations:

$$M_{max} = W_{max}L = (7.5)(8) = 60\ lb - in$$

$$M_{min} = W_{min}L = (5)(8) = 40\ lb - in,$$

where *W* denotes weight and *L* denotes length of ends.

The moment calculations can be used to find the mean and alternating moments.

$$M_{mean} = \frac{M_{max} + M_{min}}{2} = \frac{60 + 40}{2} = 50\ lb - in$$

$$M_{alt} = \frac{M_{max} - M_{min}}{2} = \frac{60 - 40}{2} = 10\ lb - in$$

Next, the Wahl bending factor for the inside surface, K_{bi}, must be found to calculate the maximum compressive stress in the coil at this inner surface.

$$K_{b_i} = \frac{4C^2 - C - 1}{4C(C-1)} = \frac{4(9)^2 - 9 - 1}{4(9)(9-1)} = 1.090$$

$$\sigma_{i_{max}} = K_{b_i}\frac{32M_{max}}{\pi d^3} = 1.09\frac{32(60)}{\pi(0.192)^3} = 94\ 142\ psi$$

The calculations can be done to compute the Wahl bending factor for the outside surface to find the maximum, minimum, alternating, and mean tensile stresses for the outer surface using similar equations already shown.

$$K_{b_o} = \frac{4C^2 + C - 1}{4C(C+1)} = \frac{4(9)^2 + 9 - 1}{4(9)(9+1)} = 0.9222$$

$$\sigma_{o_{min}} = K_{b_o} \frac{32M_{min}}{\pi d^3} = 0.9222 \frac{32(40)}{\pi(0.192)^3} = 53\ 087\ psi$$

$$\sigma_{o_{max}} = K_{b_o} \frac{32M_{max}}{\pi d^3} = 0.9222 \frac{32(60)}{\pi(0.192)^3} = 79\ 631\ psi$$

$$M_{o_{mean}} = \frac{M_{o_{max}} + M_{o_{min}}}{2} = \frac{79\ 631 + 53\ 087}{2} = 66\ 359\ psi$$

$$M_{o_{alt}} = \frac{M_{o_{max}} - M_{o_{min}}}{2} = \frac{79\ 631 - 53\ 087}{2} = 13\ 272\ psi$$

The ultimate strength, S_{ut}, of the music wire can be found using the equation below where A and b are known parameters and use it to find yield strength for the coil body, S_y, it is assumed the wires are stress relieved.

$$S_{ut} = Ad^b = (184\ 649)(0.192)^{-0.1625} = 241\ 441\ psi$$

$$S_y = 0.8S_{ut} = 0.8(241\ 441) = 193\ 152\ psi$$

The wire bending endurance limit, $S_{ewb'}$, can be calculated and then must be converted to a fully bending endurance strength, S_e.

$$S_{ew'_b} \cong \frac{45\ 000}{0.577} = 77\ 990\ psi$$

$$S_e = 0.5 \frac{S_{ew_b} S_{ut}}{S_{ut} - 0.5S_{ew_b}} = \frac{(77\ 990)(241\ 441)}{241\ 441 - 0.5(77\ 990)} = 46\ 506\ psi$$

Now the fatigue safety factor in bending, N_{fb}, can be calculated.

$$N_{f_b} = \frac{S_e\left(S_{ut} - \sigma_{o_{min}}\right)}{S_e\left(\sigma_{o_{mean}} - \sigma_{o_{min}}\right) + S_{ut}\sigma_{o_{alt}}} = \frac{(46\ 506)(241\ 441 - 53\ 087)}{(46\ 506)(66\ 359 - 53\ 087) + (241\ 441)(13\ 272)}$$
$$= 2.3$$

The safety factor against yielding, S_y, can also be calculated as follows.

$$N_{y_b} = \frac{S_y}{\sigma_{i_{max}}} = \frac{241\ 441}{94\ 142} = 2.0$$

Because these safety factors are greater than 1, the design is so far acceptable.

Now the spring rate *k* can be calculated using the required maximum and minimum moments previously calculated,

$$k = \frac{\Delta M}{\theta} = \frac{60 - 40}{0.25} = 80\ lb - in/rev$$

Where θ is the number of revolutions required, which in this case is 0.25 (or 90 degrees).

The number of active coils to obtain this spring rate can be calculated using the following equation:

$$N_a = \frac{d^4 E}{10.8Dk} = \frac{(0.192)^4(30 \times 10^6)}{(10.8)(1.728)(80)} = 27.31$$

where the modulus of elasticity, E, for music wire is known.

And the contribution from the ends of the spring can be calculated as follows:

$$N_e = \frac{2L}{3\pi D} = \frac{2(8)}{3\pi(1.728)} = 0.982$$

Thus the number of body coils in this spring, N_b, are:

$$N_b = N_a - N_e = 27.31 - 0.98 = 26$$

The maximum pin diameter to be used with this spring can be calculated using this equation

$$pin_{max} = D_i - 0.05D = 1.536 - 0.05(1.728) = 1.37\ in$$

This pin diameter also confirms a successful design because the rod about which the seat will pivot has a 1 in diameter.

Appendix G: Cabin Dimensions and Materials Estimates

Dimensions – Pod/Cabin

Height	95 in
Length	108 in
Width	56 in
Capacity	4 people
Empty Weight	1,100lbs (current estimate)
Weight (Full)	2,100lbs (current estimate)
Floor to ceiling height	78.7 in
Door Opening Height	69.5 in
Door Opening Width	34 in
Interior Volume	150 ft^2
Coefficient of Drag	1.05
Drag Force (Assuming 56 x 95 in @ 35 mph)	560.5 N

Frame – Cabin

Frame Tubing Size	1 ½" OD x 0.095" Wall Thickness
Frame Weight	328 lbs

Exterior – Cabin

Panel Thickness	0.125"
Panel Surface Area	11934.22 in^2
Panel Weight	239.6 lbs
Window Width	20.5 in
Window Height	54.7 in
Window Surface Area (per window)	1120.5 in^2
Window Surface Area (total)	7948.6 in^2

Interior – Cabin

Panel Thickness	0.125"
Panel Surface Area	4113.5 in^2
Panel Weight	91.9 lbs

Floor Area	4320 in^2

BOM – Cabin

Item	**Material**	**Supplier**	**Unit Cost**	**Total Cost**
Frame Tubing	4130 Chro-Moly Steel	Chassis Shop	$0.68/in	$1887.00
Exterior Panel	ABS (SP-6710)	Spartech	$1.90/$ft^2$	$157.48
Interior Panel	ABS (Royalite R66)	Spartech	$4.80/$ft^2$	$147.18
Floor	Altro Transflor Meta	Altro		
Seat Fabric	Vinyl		$12/yard	$33.12
Windows	Acrylic	Spartech	$18.00/$ft^2$	$993.58
Hand Rail	6061 Aluminum	Metals Depot	$73 for 24ft	$73.00
HVAC	HVAC System		$500/unit	$500
			Total per pod	**$3651.36**

LCD Monitors	22” Samsung Panel Mount	RackmountMart.com	$498/unit	$498

Appendix H: Linear Induction Efficiency

The main purpose of the propulsion calculations is to determine the synchronous velocity of the electric field produced and the overall efficiency. To reach the final calculations, input variables from the propulsion design specifications were used. In total force used was the force required to accelerate plus the frictional force. The reflected resistance refers to the resistance of one pole reflected back to the stator multiplied by the number of poles. The slip velocity divides the product of the peak current, the stator winding resistance, and the velocity by the power input. The total harmonic distortion (THD), measures the power quality of the system. For a linear induction motor three-phase power supply the THD is estimated to be 10.

Equation 6

$$Peak\ Current = \frac{Force_{Total}}{weight * Number\ of\ turns * poles * Flux\ Density * 2}$$

Equation 7

$$3 - phase\ power\ loss\ in\ rotor = 3 * Resistance * Peak\ Current$$

Equation 8

$$Synchronous\ Velocity = \frac{Power_{Dev} * Slip\ Velocity}{3 * Peak\ Current^2 * Reflected\ Resistance}$$

Equation 9

$$Harmonic\ Power = 3 * Current^2 * Resistance * \frac{THD}{100}$$

Equation 10

$$Efficiency = \frac{Power_{Dev}}{Power_{Dev} + Power_{Har} + Power_{Stator} + Power_{Rotor} + Power_{Transmitted}}$$

Appendix I: Structure Calculations

Calculations on the column

For the calculations of the structure a distance between the columns will be considered to be 49 ft. at maximum. The spacing between the bogies will be assumed to be 7 ft. at maximum capacity. Therefore, the cabs supported by each of the columns would be 7 at a certain time. The weight of each cab will be assumed to be 4 kips. Then, the total vertical live load that one column would have resists is 7*4 kips = 28 kips. Additionally, 10 kips will be added to account for the self-weight of the structure as the dead load. The theoretical static system is presented in figure 8.

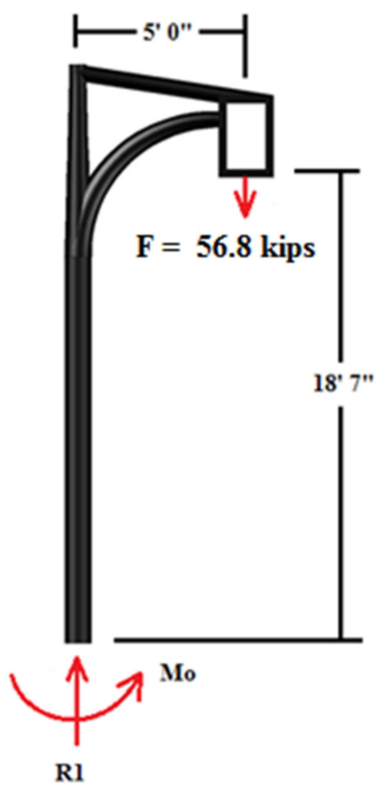


Figure 166 Static Analysis on columns

The reactions at the base can be found by a simple static analysis; first, a load combination will be calculated to introduce an adequate factor of safety.

$$F_{max} = 1.2\ DL + 1.6\ LL = 1.2(10) + 1.6(28) = 56.8\ \text{kips} \qquad (1)$$

Then, by adding up the forces in the y-direction, the vertical reaction, R1, that will be transferred to the foundation is 56.8 kips.

By performing the sum of the moments at any point, the bending moment experienced by the columns is:

$$Mo = (56.8\ \text{kips})(5') = 284\ \text{kip} - \text{ft}$$

This same moment is felt by the column at any point along its straight length. The following calculation can be performed to find the thickness that the straight portion of the column needs to have.

Yield Check

$$\sigma = \frac{Mc}{I} - \frac{F}{A} = \frac{M_o c}{\frac{\pi}{4} * (r_{out}^4 - r_{in}^4)} - \frac{F}{\pi * (r_{out}^2 - r_{in}^2)}$$

Where "t" is the required thickness of the column

Now consider structural steel grade 50 as the material to be used. The yield strength of this type of steel is F_y = 50 ksi = 7200 kip/ft and the ultimate strength, F_u = 65 ksi = 9360 kip/ft.

$$7200\ \text{kip/ft} = \frac{(284\ \text{kip} - \text{ft}) * (1.5/2)\ \text{ft}}{\frac{\pi}{4} * (0.75^4 - r_{in}^4)} - \frac{56.8\ \text{kips}}{\pi * (0.75^2 - r_{in}^2)}$$

Solving for the internal radius: r_{in} = 0.73 ft = 8.76 in. Then, the required thickness for the column is (1.5/2)*12 in. – 8.76 in. = 0.24". Therefore, the thickness of the pipes for the column has to be 0.24" or more.

Pratt Truss Computer Analysis

The assigned loads shown in **Error! Reference source not found.** are intended to mimic the passage of cabs across the guideway. Then the expected deflection of the guideway can be calculated using the method of virtual work or a computer software such as SAP 2000. The following analysis was conducted using the latter.

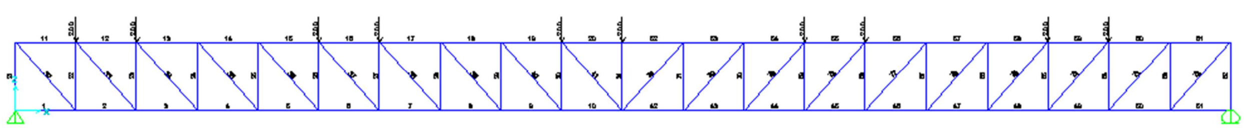


Figure 167 Live loads over the guideway

One half of the truss is presented so the section number can be visualized.

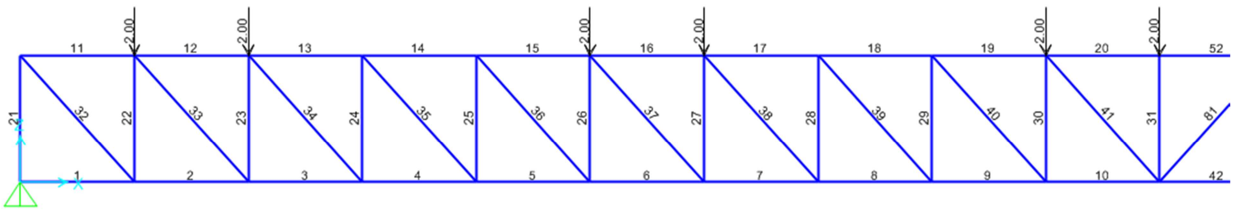


Figure 168 Live Loads and section numbers over one half of the bridge

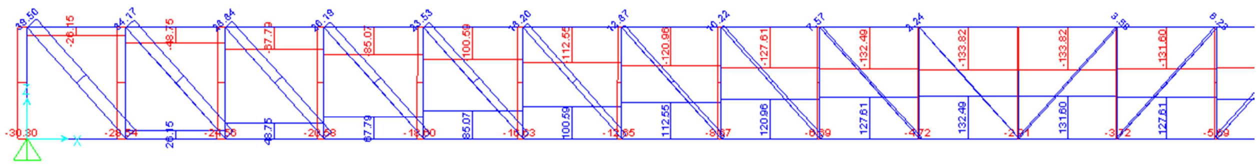


Figure 169 Axial force diagrams due to live loads on one half of the truss

Table 27 Axial forces for truss design (one half of the truss)

TABLE: Element Forces - Frames							
Frame	P	Frame	P	Frame	P	Frame	P
Text	Kip	Text	Kip	Text	Kip	Text	Kip
1	-1.426E-12	11	-26.149	21	-30.301	31	-2.907
2	26.149	12	-48.746	22	-28.537	32	39.022
3	48.746	13	-67.792	23	-24.56	33	33.689
4	67.792	14	-85.072	24	-20.582	34	28.357
5	85.072	15	-100.587	25	-18.605	35	25.706
6	100.587	16	-112.55	26	-16.627	36	23.055
7	112.55	17	-120.962	27	-12.65	37	17.723
8	120.962	18	-127.608	28	-8.672	38	12.391
9	127.608	19	-132.489	29	-6.695	39	9.74
10	132.489	20	-133.818	30	-4.717	40	7.088

Appendix J: Preliminary Environmental Impact Report (EIR)

Initial Environmental Impacts Report

Introduction

The following analysis is a California Environmental Quality Act (CEQA) style Environmental Impact Report (EIR) that examines the potential environmental effects – both natural and urban – of the proposed Sustainable Mobility System for Silicon Valley (SMSSV) project for a demo site in Sunnyvale, California. The four main purposes of CEQA are:

> 1. To inform governmental decision-makers and the public about the potential, significant environmental effects of proposed activities;
> 2. To identify the ways that environmental damage can be avoided and significantly reduced;
> 3. To prevent significant, avoidable damage to the environment by requiring changes in projects through the use of alternatives or mitigation measures when the governmental agency finds the changes to be feasible; and
> 4. To disclose the public reasons why a governmental agency approved the project in the manner the agency chose if significant environmental effects are involved.
>
> (CEQA Title 14. California Code of Regulations. Chapter 3; section 15002, 2005)

The following document accomplishes all four of these requirements by analyzing six specific environmental resource areas while meticulously adhering to the step-by-step CEQA analysis process.

As aforementioned, this report focuses on six resource sections: Land Use, Aesthetics, Population and Housing, Transportation and Circulation, Noise, and Air Quality. For each of these sections, a project description is specified and then each is divided into subsections that analyze the impacts of the proposed project description. These subsections are then broken down into the traditional CEQA format where an environmental setting – or background – is given, thresholds are stated based on those established in CEQA Appendix G, the significance levels are determined for each of these thresholds, the impact explanation is given for why this significance level was chosen, mitigation measures are discussed if applicable, and monitoring plans are proposed.

Identifying Information/Location Contacts

1. Project title: Sustainable Mobility System for Silicon Valley (SMSSV)

2. Lead agency name and address: San Jose State University: 1 Washington Square, San Jose, CA 95112

3. Contact person: Emma Reed

4. Project location: The section of Mathilda Avenue in Sunnyvale bounded by the Caltrain tracks and El Camino (Route 82)

5. Project sponsor's name and address: San Jose State University: 1 Washington Square, San Jose, CA 95112

6. General plan designation: Current land use for the section includes: Central Business, Civic Center, Office, Low-Medium Density Residential, and High Density Residential

7. Zoning: No immediate rezoning will be required for the implementation of this project; some areas might require rezoning in the future if TODs are to be developed.

8. Description of project: The Sustainable Mobility System for Silicon Valley (SMSSV) is an interdisciplinary project for San Jose State University to design a Personal Rapid Transport (PRT) system using renewable resources.

9. Surrounding land uses and setting: Briefly describe the project's surroundings: The land uses surrounding the proposed project site are mixed use ranging from high density residential to low-medium density residential to office to central business district to civic center designations.

10. Other public agencies whose approval is required (e.g., permits, financing approval, or participation agreement.): City of Sunnyvale; Santa Clara County; State of California/CEQA; Pacific Gas & Electric; Sunnyvale Economic Development Committee; Environmental Services Department; California Department of Fish and Wildlife; BAAQMD; CalTrans; VTA; CARB.

Project Description

Present mobility options, especially in dense urban areas are becoming more and more unsustainable. Major issues that plague present options include traffic congestion, loss of productivity from time spent commuting and/or parking, continued use of and dependence on hydrocarbon fuels, increased possibility of accidents that injure people and damage property, decrease in quality of life for residents (wasted time, increased stress, noise, smog, safety), high cost of ownership for private vehicles (especially new 'green' vehicles such as electric vehicles and hybrid electric vehicles), excessive consumption of raw materials in the production of automobiles, environmental degradation from greenhouse gas emissions and by-products from the wear-out of parts, and inadequate mass transportation options (slow, limited service area, and relatively high cost).

Fundamentally different approaches to personal mobility are needed to address the problems listed above and achieve sustainability. An automated transportation network (ATN) system utilizing 'pod cars' is one such approach to reducing the detrimental effects of these issues our society faces on a daily basis (see for example: Irving, et al (1978), Rydell (2000), and Shawber (2012).

We propose to develop and bring to market the elements of a solar powered ATN system that will be scalable, replicable, and that can be located within the existing rights of way in current urban locales. Our trial project site is located in the city of Sunnyvale, California along an area known as the 'Mathilda Corridor' along Mathilda Avenue. The hope is that the project – assuming success – will be replicated in cities throughout California, the nation, and even nationally as a means of reducing congestion and greenhouse gas emissions.

The six main resource sections that this environmental impact report initial study aims to focus on include land use, aesthetics, transportation and circulation, housing, noise, and air quality as they relate to potentially significant effects on the surrounding region.

(http://www.engr.sjsu.edu/smssv/project.html)

The proposed project could potentially affect any and all of the environmental factors listed. The following pages present a more detailed checklist and discussion of each of the six environmental factors checked below.

☒	Land Use	☒	Air Quality	☐	Biological Resources
☒	Aesthetics	☐	Greenhouse Gas Emissions	☐	Geology and Soils
☒	Population and Housing	☐	Wind and Shadow	☐	Hydrology and Water Quality
☐	Cultural and Paleo. Resources	☐	Recreation	☐	Hazards/Hazardous Materials
☒	Transportation and Circulation	☐	Utilities and Service Systems	☐	Mineral/Energy Resources
☒	Noise	☐	Public Services	☐	Agricultural and Forest Resources

Land Use

Proposed Project

Topics:	*Potentially Significant Impact*	*Less Than Significant with Mitigation Incorporated*	*Less Than Significant Impact*	*No Impact*
1. LAND USE AND LAND USE PLANNING— Would the project:				
a) Physically divide an established community?	☐	☐	☐	☒
b) Conflict with any applicable land use plan, policy, or regulation of an agency with jurisdiction over the project (including, but not limited to the general plan, specific plan, local coastal program, or zoning ordinance) adopted for the purpose of avoiding or mitigating an environmental effect?	☐	☒	☐	☐
c) Have a substantial impact upon the existing character of the vicinity?	☒	☐	☐	☐

Environmental Setting:

Sunnyvale is a relatively young city, incorporated in 1912. Its mild climate and fertile soil, nonetheless, have provided a comfortable and productive location for human settlement for thousands of years. Early settlers actually were drawn to the region by the mild climate, plentiful sunshine, and the rich soil. Sunnyvale development began in earnest in 1864, at the same time the Central Railroad built a line connecting San Francisco to San Jose. After the 1906 earthquake, industry arrived in Sunnyvale – the first of which included the Hendy Ironworks and the Libby Cannery, which were placed in the center of town near the railroad. The city's downtown continued to grow as a mix of uses in close proximity and walking distance of one another. Additionally, transportation routes played an important role in Sunnyvale's development. The first transportation facilities included the railroad and El Camino Real. By the 1940s, Sunnyvale had shifted from an agricultural community to an industrial center, with an economy emphasizing the exploding defense and aerospace industries. Approximately 65 percent of the city's current housing and 50 percent of its non-residential developments were constructed between 1950 and 1969. These new buildings covered large portions of the region and led to significant alterations to the character and form of the city. Unlike the mix of uses within the city center, new districts were built in large tracts of land designed exclusively for residential, commercial, or industrial uses. Over the last three decades, Sunnyvale's economy has undergone yet another shift, as high technology companies have launched the Silicon Valley era (Sunnyvale General Plan, 2011, pp. 2-3 – 2-4).

Thresholds of Significance:

LAND-1: If the project would physically divide an established community, then its impact is considered potentially significant.

LAND-2: If the project would conflict with any applicable land use plan, policy, or regulation of an agency with jurisdiction over the project (including, but not limited to the general plan, specific plan, local coastal program, or zoning ordinance) adopted for the

purpose of avoiding or mitigating an environmental effect, then its impact is considered potentially significant.
LAND-3: If the project would have a substantial impact upon the existing character of the vicinity, then its impact is considered potentially significant.

Significance Level:

LAND-1: No impact.
LAND-2: Less than significant with mitigation incorporated.
LAND-3: Potentially significant impact.

Impact Explanation:

LAND-1: The project plans will not physically divide the established Mathilda Avenue community, as ATN developers will be building the transportation well above the ground level. This will enable people to walk below it while only noticing the occasional foundational pillar.
LAND-2: As long as general zoning requirements and regulations are followed to ensure that Mathilda Avenue is zoned to allow public transit networks, then the potentially significant impacts of this aspect will be mitigated. This area currently is zoned as "central business (Sunnyvale General Plan, 2011, pp. 3-9).
LAND-3: The project will have a potentially significant impact on the preexisting character of the vicinity since it will be introducing a new type of transit system not commonly used in the Bay Area, California, or the United States overall. Although the effects of implementing the ATN along the Mathilda Corridor will be significant, the change in character should be a dramatic improvement for congestion and air pollution in the vicinity.

Mitigations:

LAND-2: A major policy goal set out in the Sunnyvale General plan is that of contributing to "efforts to minimize region-wide average trip length and single-occupant vehicle trips" (pp. 3-5). Because this project's overall aim is to improve the character and efficiency of the vicinity, obtaining the appropriate zoning for the project should not be an issues as long as appropriate protocols are followed.

Monitoring Plans:

LAND-2: The project developer must submit a General Plan amendment report with re-zoning designations or zoning amendments to the City of Sunnyvale's Department of Development – Planning division, in order to demonstrate the official alteration of the land parcels within the Mathilda Corridor vicinity as well as to demonstrate the project's approval by the city council.

Aesthetics

Proposed Project

Topics:	Potentially Significant Impact	Less Than Significant with Mitigation Incorporated	Less Than Significant Impact	No Impact
2. AESTHETICS—Would the project:				
a) Have a substantial adverse effect on a scenic vista?	☐	☐	☒	☐
b) Substantially damage scenic resources, including, but not limited to, trees, rock outcroppings, and other features of the built or natural environment which contribute to a scenic public setting?	☒	☐	☐	☐
c) Substantially degrade the existing visual character or quality of the site and its surroundings?	☐	☐	☒	☐
d) Create a new source of substantial light or glare which would adversely affect day or nighttime views in the area or which would substantially impact other people or properties?	☐	☒	☐	☐

Environmental Setting:

Sunnyvale is a relatively young city, incorporated in 1912. Its mild climate and fertile soil, nonetheless, have provided a comfortable and productive location for human settlement for thousands of years. Early settlers actually were drawn to the region by the mild climate, plentiful sunshine, and the rich soil. Sunnyvale development began in earnest in 1864, at the same time the Central Railroad built a line connecting San Francisco to San Jose. After the 1906 earthquake, industry arrived in Sunnyvale – the first of which included the Hendy Ironworks and the Libby Cannery, which were placed in the center of town near the railroad. The city's downtown continued to grow as a mix of uses in close proximity and walking distance of one another. Additionally, transportation routes played an important role in Sunnyvale's development. The first transportation facilities included the railroad and El Camino Real. By the 1940s, Sunnyvale had shifted from an agricultural community to an industrial center, with an economy emphasizing the exploding defense and aerospace industries. Approximately 65 percent of the city's current housing and 50 percent of its non-residential developments were constructed between 1950 and 1969. These new buildings covered large portions of the region and led to significant alterations to the character and form of the city. Unlike the mix of uses within the city center, new districts were built in large tracts of land designed exclusively for residential, commercial, or industrial uses. Over the last three decades, Sunnyvale's economy has undergone yet another shift, as high technology companies have launched the Silicon Valley era (Sunnyvale General Plan, 2011, pp. 2-3 – 2-4).

Thresholds of Significance:

AES-1: If the project would have a substantial adverse effect on a scenic vista, then its impact is considered potentially significant.

AES-2: If the project would substantially damage scenic resources, including, but not limited to, trees, rock outcroppings, and other features of the built or natural environment which contribute to a scenic public setting, then its impact is considered potentially significant.

AES-3: If the project would substantially degrade the existing visual character or quality of the site and its surroundings, then its impact is considered potentially significant.

AES-4: If the project would create a new source of substantial light or glare which would adversely affect day or nighttime views in the area or which would substantially impact other people or properties, then its impact is considered potentially significant.

Significance Level:

AES-1: Less than significant impact.

AES-2: Potentially significant impact.

AES-3: Less than significant impact.

AES-4: Potentially significant with mitigation incorporated.

Impact Explanation:

AES-1: The project's impact on the scenic vista will be minimal since it will be running parallel to Mathilda Avenue. The only possible impact of the project on the view from the Mathilda Corridor is in locations where the ATN crosses the road. Since it is located high up, there is the potential that it could block some of the view looking at the hills east of the area.

AES-2: In order to install the ATN in along Mathilda Avenue, many trees likely will have to be removed to place foundations and to ensure that cars can run smoothly along the rails without running into tree branches. Thus, the damage to scenic resources is potentially significant for this project.

AES-3: Other than tree removal, there are not any other expected significant impacts of the ATN project on the visual character of the site and its surroundings – especially since the tracks and rails will be located far above eye level.

AES-4: It is highly possible that lighting for this project will add to light pollution in this area – especially during nighttime hours. Assuming that the ATN runs late into night – or even 24 hours per day – a significant amount of lighting will be required for safety and security purposes. It will also light the street considerably since all this lighting will be located up high.

Mitigations:

AES-4: The Sunnyvale City Council should request that motion sensors are used and connected to the lights in every area to avoid the use of unnecessary lighting throughout the path of the ATN.

Monitoring Plans:

AES-4: Light glare and excessive lighting are significant concerns with this project. These effects can quite easily be avoided from every section of the ATN by implementing motion sensors linked to lighting; however, there may be legal concerns with respect to lighting in public areas.

Transportation and Circulation

Proposed Project

Topics:	*Potentially Significant Impact*	*Less Than Significant with Mitigation Incorporated*	*Less Than Significant Impact*	*No Impact*
5. TRANSPORTATION AND CIRCULATION— Would the project:				
a) Conflict with an applicable plan, ordinance or policy establishing measures of effectiveness for the performance of the circulation system, taking into account all modes of transportation including mass transit and non-motorized travel and relevant components of the circulation system, including but not limited to intersections, streets, highways and freeways, pedestrian and bicycle paths, and mass transit?	☐	☐	☒	☐
b) Conflict with an applicable congestion management program, including but not limited to level of service standards and travel demand measures, or other standards established by the county congestion management agency for designated roads or highways?	☐	☐	☐	☒
c) Result in a change in air traffic patterns, including either an increase in traffic levels, obstructions to flight, or a change in location, that results in substantial safety risks?	☐	☐	☐	☒
d) Substantially increase hazards due to a design feature (e.g., sharp curves or dangerous intersections) or incompatible uses?	☐	☒	☐	☐
e) Result in inadequate emergency access?	☐	☐	☐	☒
f) Conflict with adopted policies, plans, or programs regarding public transit, bicycle, or pedestrian facilities, or otherwise decrease the performance or safety of such facilities?	☐	☐	☒	☐

Environmental Setting:

Sunnyvale is a relatively young city, incorporated in 1912. Its mild climate and fertile soil, nonetheless, have provided a comfortable and productive location for human settlement for thousands of years. Early settlers actually were drawn to the region by the mild climate, plentiful sunshine, and the rich soil. Sunnyvale development began in earnest in 1864, at the same time the Central Railroad built a line connecting San Francisco to San Jose. After the 1906 earthquake, industry arrived in Sunnyvale – the first of which included the Hendy Ironworks and the Libby Cannery, which were placed in the center of town near the railroad. The city's downtown continued to grow as a mix of uses in close proximity and walking distance of one another. Additionally, transportation routes played an important role in Sunnyvale's development. The first transportation facilities included the railroad and El

Camino Real. By the 1940s, Sunnyvale had shifted from an agricultural community to an industrial center, with an economy emphasizing the exploding defense and aerospace industries. Approximately 65 percent of the city's current housing and 50 percent of its non-residential developments were constructed between 1950 and 1969. These new buildings covered large portions of the region and led to significant alterations to the character and form of the city. Unlike the mix of uses within the city center, new districts were built in large tracts of land designed exclusively for residential, commercial, or industrial uses. Over the last three decades, Sunnyvale's economy has undergone yet another shift, as high technology companies have launched the Silicon Valley era (Sunnyvale General Plan, 2011, pp. 2-3 – 2-4).

Thresholds of Significance:

TRANS-1: If the project would conflict with an applicable plan, ordinance or policy establishing measures of effectiveness for the performance of the circulation system, taking into account all modes of transportation including mass transit and non-motorized travel and relevant components of the circulation system, including but not limited to intersections, streets, highways and freeways, pedestrian and bicycle paths, and mass transit, then its impact is considered potentially significant.

TRANS-2: If the project would conflict with an applicable congestion management program, including but not limited to level of service standards and travel demand measures, or other standards established by the county congestion management agency for designated roads or highways, then its impact is considered potentially significant.

TRANS-3: If the project would result in a change in air traffic patterns, including either an increase in traffic levels, obstructions to flight, or a change in location, that results in substantial safety risks, then its impact is considered potentially significant.

TRANS-4: If the project would substantially increase hazards due to a design feature (e.g., sharp curves or dangerous intersections) or incompatible uses, then its impact is considered potentially significant.

TRANS-5: If the project would result in inadequate emergency access, then its impact is considered potentially significant.

TRANS-6: If the project would conflict with adopted policies, plans, or programs regarding public transit, bicycle, or pedestrian facilities, or otherwise decrease the performance or safety of such facilities, then its impact is considered potentially significant.

Significance Level:

TRANS-1: Less than significant impact.
TRANS-2: No impact.
TRANS-3: No impact.
TRANS-4: Less than significant with mitigation incorporated
TRANS-5: No impact.
TRANS-6: Less than significant impact.

Impact Explanation:

TRANS-1: There does not appear to exist a specific policy or regulation in the city of Sunnyvale's General Plan text with which this transit project will conflict. To the contrary, it seems to be in line with several of the city's goals laid out within the General Plan documentation.

TRANS-2: This project will not conflict with a preexisting congestion management program. In fact, it will do quite the opposite. The aim of this transit project is to significantly reduce traffic congestion within the Mathilda corridor, so the chance of any negative congestion-related impacts is small.
TRANS-3: The project will have no impact on air traffic patterns in the Sunnyvale region.
TRANS-4: As long as proper safety precautions, which have been highlighted in the project plan, are followed, then there should be no significant impacts to safety of citizens in the area.
TRANS-5: The pod cars will travel significantly elevated above ground level; thus, they should not have any impact on private cars or emergency vehicles/emergency access in the region.
TRANS-6: The project should not conflict with any policies, plans, or programs regarding public transit laid out by the city of Sunnyvale. Policy LT-5.2 actually states that plans should "integrate the use of land and the transportation system" Sunnyvale General Plan, 2011, pp. 3-19). This project is well in line with this policy.

Mitigations:

TRANS-4: Safety precautions are a huge priority of the transit project design for this personal rapid transit ATN. There will also be precautions laid out by several different regulatory agencies that must be adhered to before this form of transportation can be made an option to the public.

Monitoring Plans:

TRANS-4: The Santa Clara Valley Transportation Authority (VTA) will be in charge of checking to make sure the appropriate safety precautions are implemented for this project and then monitoring to ensure proper maintenance is conducted periodically. This will prevent accidents and unnecessary equipment failures.

Noise

Proposed Project

Topics:	Potentially Significant Impact	Less Than Significant with Mitigation Incorporated	Less Than Significant Impact	No Impact
6. NOISE—Would the project:				
a) Result in exposure of persons to or generation of noise levels in excess of standards established in the local general plan or noise ordinance, or applicable standards of other agencies?	☐	☐	☒	☐
b) Result in exposure of persons to or generation of excessive groundborne vibration or groundborne noise levels?	☐	☐	☒	☐
c) Result in a substantial permanent increase in ambient noise levels in the project vicinity above levels existing without the project?	☐	☐	☒	☐
d) Result in a substantial temporary or periodic increase in ambient noise levels in the project vicinity above levels existing without the project?	☐	☒	☐	☐
e) For a project located within an airport land use plan area, or, where such a plan has not been adopted, in an area within two miles of a public airport or public use airport, would the project expose people residing or working in the area to excessive noise levels?	☐	☐	☐	☒
f) For a project located in the vicinity of a private airstrip, would the project expose people residing or working in the project area to excessive noise levels?	☐	☐	☐	☒
g) Be substantially affected by existing noise levels?	☐	☐	☐	☒

Environmental Setting:

Sunnyvale is a relatively young city, incorporated in 1912. Its mild climate and fertile soil, nonetheless, have provided a comfortable and productive location for human settlement for thousands of years. Early settlers actually were drawn to the region by the mild climate, plentiful sunshine, and the rich soil. Sunnyvale development began in earnest in 1864, at the same time the Central Railroad built a line connecting San Francisco to San Jose. After the 1906 earthquake, industry arrived in Sunnyvale – the first of which included the Hendy Ironworks and the Libby Cannery, which were placed in the center of town near the railroad. The city's downtown continued to grow as a mix of uses in close proximity and walking distance of one another. Additionally, transportation routes played an important role in Sunnyvale's development. The first transportation facilities included the railroad and El Camino Real. By the 1940s, Sunnyvale had shifted from an agricultural community to an industrial center, with an economy emphasizing the exploding defense and aerospace industries. Approximately 65 percent of the city's current housing and 50 percent of its non-residential developments were constructed between 1950 and 1969. These new buildings covered large portions of the region and led to significant alterations to the character and form of the city. Unlike the mix of uses within the city center, new districts were built in large tracts of land designed exclusively for residential, commercial, or industrial uses. Over the last three decades, Sunnyvale's economy has undergone yet another shift, as high technology companies have launched the Silicon Valley era (Sunnyvale General Plan, 2011, pp. 2-3 – 2-4).

Thresholds of Significance:

NOISE-1: If the project would result in exposure of persons to or generation of noise levels in excess of standards established in the local general plan or noise ordinance, or applicable standards of other agencies, then its impact is considered potentially significant.
NOISE-2: If the project would result in exposure of persons to or generation of excessive groundborne vibration or groundborne noise levels, then its impact is considered potentially significant.
NOISE-3: If the project would result in a substantial permanent increase in ambient noise levels in the project vicinity above levels existing without the project, then its impact is considered potentially significant.
NOISE-4: If the project would result in a substantial temporary or periodic increase in ambient noise levels in the project vicinity above levels existing without the project, then its impact is considered potentially significant.
NOISE-5: If the project would, for a project located within an airport land use plan area, or, where such a plan has not been adopted, in an area within two miles of a public airport or public use airport, expose people residing or working in the area to excessive noise levels, its impact is considered potentially significant.
NOISE-6: If the project would, for a project located in the vicinity of a private airstrip, expose people residing or working in the project area to excessive noise levels, then its impact is considered potentially significant.
NOISE-7: If the project would be substantially affected by existing noise levels, then its impact is considered potentially significant.

Significance Level:

NOISE-1: Less than significant impact.
NOISE-2: Less than significant impact.
NOISE-3: Less than significant impact.
NOISE-4: Less than significant with mitigation incorporated.
NOISE-5: No impact.
NOISE-6: No impact.
NOISE-7: No impact.

Impact Explanation:

NOISE-1: The city of Sunnyvale tolerates a limit of 70 dBA for areas affected by train noise. The ATN is expected to be significantly quieter than a train and is located within the same neighborhood as the Caltrain runs; thus, the noise produced by the project should be less than significant to those in the region.
NOISE-2: Once again, since this project will be located within the same neighborhood as the Caltrain runs, the vibrations and groundborne noise it produces should be minimal compared to the train.

NOISE-3: Although the ATN will undoubtedly add noise to the area, the amount of noise it offsets through reducing private car trips likely will offset this additional noise, making it less than significant.
NOISE-4: It is probable that noise during construction could be more significant than the aforementioned impacts. Dirt will need to be excavated in order to implement foundations for the ATN, and there will inevitably be substantial noise as a result. Similarly, loud noise and vibration also can be expected from concrete delivery and pumping.
NOISE-5: There is no impact to the environment because the project is not located within an airport land use area.
NOISE-6: There is no impact to the environment because the project is not located within the vicinity of a private airstrip.
NOISE-7: It is not likely that the project will be affected in any way by existing noise levels in the vicinity.

Mitigations:

NOISE-4: Barrier walls or add-on noise reducing devices should be designed and implemented to attain a noise level during operation of below the maximum set by the city of Sunnyvale when measured in outdoor areas of bordering residential parcels.

Monitoring Plans:

NOISE-4: The goal is that the city and/or county will check the noise levels emitted by the ATN once the project has been completed to ensure they do not exceed the maximum standard set out by the city of Sunnyvale.

Population And Housing

Proposed Project

Topics:	*Potentially Significant Impact*	*Less Than Significant with Mitigation Incorporated*	*Less Than Significant Impact*	*No Impact*
3. POPULATION AND HOUSING—Would the project:				
a) Induce substantial population growth in an area, either directly (for example, by proposing new homes and businesses) or indirectly (for example, through extension of roads or other infrastructure)?	☐	☒	☐	☐
b) Displace substantial numbers of existing housing units or create demand for additional housing, necessitating the construction of replacement housing?	☐	☐	☒	☐
c) Displace substantial numbers of people, necessitating the construction of replacement housing elsewhere?	☐	☐	☐	☒

Environmental Setting:

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Thresholds of Significance:

HOUSE-1: If the project would induce substantial population growth in an area, either directly (for example, by proposing new homes and businesses) or indirectly (for example,

through extension of roads or other infrastructure), then its impact is considered potentially significant.
HOUSE-2: If the project would displace substantial numbers of existing housing units or create demand for additional housing, necessitating the construction of replacement housing, then its impact is considered potentially significant.
HOUSE-3: If the project would displace substantial numbers of people, necessitating the construction of replacement housing elsewhere, then its impact is considered potentially significant.

Significance Level:

HOUSE-1: Less than significant with mitigation incorporated.
HOUSE-2: Less than significant impact.
HOUSE-3: No impact.

Impact Explanation:

HOUSE-1: It is likely that if the ATN project is successful, more people will want to move closer to it, thus, significantly increasing population density in the area. As long as zoning and population growth are managed appropriately, however, the impact to the city should not be detrimental. It is also likely that as the ATN becomes more popular, more routes and rail lines will be constructed throughout the region.
HOUSE-2: It is possible that the ATN project will attract more people to the area requiring higher-density housing in the long-term.
HOUSE-3: The ATN will run along the side of Mathilda Avenue and, therefore, should not require the displacement of housing units.

Mitigations:

HOUSE-1: The City of Sunnyvale's Department of Development – Planning division must ensure that the region does not become significantly impacted by too many people being drawn to the Mathilda Corridor as it transforms into a transit-oriented development (TOD). This can be accomplished by enforcing preexisting and implementing new, effective housing-related zoning ordinances.

Monitoring Plans:

HOUSE-1: The project developer must submit a General Plan amendment report with re-zoning designations or zoning amendments to the City of Sunnyvale's Department of Development – Planning division in order for higher-density housing to be constructed or for entirely new housing developments to take place. The Planning division will be responsible for monitoring the housing impacts through the amendments to the General Plan that take place.

Air Quality

Proposed Project

Topics:	Potentially Significant Impact	Less Than Significant with Mitigation Incorporated	Less Than Significant Impact	No Impact
7. AIR QUALITY—Would the project:				
a) Conflict with or obstruct implementation of the applicable air quality plan?	☐	☒	☐	☐
b) Violate any air quality standard or contribute substantially to an existing or projected air quality violation?	☐	☐	☐	☒
c) Result in a cumulatively considerable net increase of any criteria pollutant for which the project region is non-attainment under an applicable federal, state, or regional ambient air quality standard (including releasing emissions which exceed quantitative thresholds for ozone precursors)?	☐	☐	☐	☒
d) Expose sensitive receptors to substantial pollutant concentrations?	☐	☐	☐	☒
e) Create objectionable odors affecting a substantial number of people?	☐	☐	☒	☐

Environmental Setting:

Sunnyvale is a relatively young city, incorporated in 1912. Its mild climate and fertile soil, nonetheless, have provided a comfortable and productive location for human settlement for thousands of years. Early settlers actually were drawn to the region by the mild climate, plentiful sunshine, and the rich soil. Sunnyvale development began in earnest in 1864, at the same time the Central Railroad built a line connecting San Francisco to San Jose. After the 1906 earthquake, industry arrived in Sunnyvale – the first of which included the Hendy Ironworks and the Libby Cannery, which were placed in the center of town near the railroad. The city's downtown continued to grow as a mix of uses in close proximity and walking distance of one another. Additionally, transportation routes played an important role in Sunnyvale's development. The first transportation facilities included the railroad and El Camino Real. By the 1940s, Sunnyvale had shifted from an agricultural community to an industrial center, with an economy emphasizing the exploding defense and aerospace industries. Approximately 65 percent of the city's current housing and 50 percent of its non-residential developments were constructed between 1950 and 1969. These new buildings covered large portions of the region and led to significant alterations to the character and form of the city. Unlike the mix of uses within the city center, new districts were built in large tracts of land designed exclusively for residential, commercial, or industrial uses. Over the last three decades, Sunnyvale's economy has undergone yet another shift, as high technology companies have launched the Silicon Valley era (Sunnyvale General Plan, 2011, pp. 2-3 – 2-4).

Thresholds of Significance:

AIR-1: If the project would conflict with or obstruct implementation of the applicable air quality plan, then its impact is considered potentially significant.
AIR-2: If the project would violate any air quality standard or contribute substantially to an existing or projected air quality violation, then its impact is considered potentially significant.
AIR-3: If the project would result in a cumulatively considerable net increase of any criteria pollutant for which the project region is non-attainment under an applicable federal, state, or regional ambient air quality standard (including releasing emissions which exceed quantitative thresholds for ozone precursors), then its impact is considered potentially significant.
AIR-4: If the project would expose sensitive receptors to substantial pollutant concentrations, then its impact is considered potentially significant.
AIR-5: If the project would create objectionable odors affecting a substantial number of people, then its impact is considered potentially significant.

Significance Level:

AIR-1: Less than significant with mitigation incorporated.
AIR-2: No impact.
AIR-3: No impact.
AIR-4: No impact.
AIR-5: Less than significant impact.

Impact Explanation:

AIR-1: It is possible that this project could result in temporarily decreased air quality levels due to dust and other side effects during the construction phase. Once the ATN is completed, however, it will be powered by solar energy and will result in decreased air pollution levels in the area.
AIR-2: The project will not violate any air quality standard nor will it contribute significantly to an existing or projected air quality violation. In fact, the project is completely in line with Goal EM-11 set out in the City of Sunnyvale General Plan, which states that a major aim is to "improve Sunnyvale's air quality and reduce the exposure of its citizens to air pollutants" (Sunnyvale General Plan, 2011, pp. 7-28 – 7-29).
AIR-3: The project will not result in a cumulatively considerable net increase of any criteria pollutant.
AIR-4: The project will not expose sensitive receptors to substantial pollutant concentrations.
AIR-5: There is a distinct possibility that the project may create objectionable odors affecting a substantial number of people during the construction phase, but this is unlikely and would only be temporary.

Mitigations:

AIR-1: Those in charge of bringing the project to fruition must monitor the potentially significant effects of construction extremely carefully to ensure that negative and irreversible impacts do not occur in this region.

Monitoring Plans:

AIR-1: Developers will be responsible for monitoring impacts caused by the construction process and reporting periodically to the City of Sunnyvale's Department of Development – Planning division regarding these effects.

Recommendation

For Complete EIR

Since multiple resource area sections of this Initial Study have proven to hold potentially significant environmental impacts (proposed projects for both Land Use and Aesthetics) that cannot be mitigated to less-than-significant levels at this time, a complete Environmental Impact Report (EIR) analyzing the potential impacts of every resource section must be required for this project site location in order to continue with development and construction processes.

Opportunity for Further Research

EIR Sections Requiring Additional Study

Besides the six resource sections examined above, it appears that Utilities and Service Systems and Biological Resources might be areas that require a fair amount of study. Utilities and Service Systems is important because the construction of this PRT project along Mathilda Avenue may result in power lines, gas lines, lamp posts, and other utilities needing to be relocated. Biological Resources also is a significant section to research since the building of this project might interfere with the habits of certain animals (especially birds' flight paths because it is elevated), and trees since they might be in the way of the planned transit route.

Appendix K: Funding ATNs

Introduction

The Sustainable Mobility System for Silicon Valley (SMSSV) is an Automated Transportation Network (ATN) located within the City of Sunnyvale, California along Mathilda Avenue, also known as the ‘Mathilda Corridor’. In the sections below, the funding for a trial project along the Mathilda Corridor is discussed. Federal, regional, and local funding sources, as well as competitive grants are described and their applicability to the SMSSV project discussed. Public-Private Partnership opportunities are also reviewed. Finally, recommendations on next steps are outlined. This discussion is meant to provide an overview of the SMSSV funding landscape and potential paths forward to implementation and operation. Over time, new funding opportunities will emerge, while current opportunities may expire. Monitoring funding opportunities throughout the development of the SMSSV project will be key to its success.

Federal Funding

The existing transportation funding programs that are potentially applicable to the SMSSV project are discussed below. Any potential hurdles to accessing the funding are also discussed. Traditionally, the federal government has provided funding for major transportation investments. The Safe, Accountable, Flexible, Efficient Transportation Equity Act (SAFETEA-LU) was the federal legislation through which these funds were distributed. The legislation was set to expire in 2009, but was extended 10 times until it was replaced by the Moving Ahead for Progress in the 21st Century Act (MAP-21) in 2012. MAP-21 is set to expire in 2014 and much of the specifics regarding accessing the funds are still under development. Given the political volatility in Washington D.C., long-term projections regarding transportation funding sources at the national level should be viewed with a level of skepticism.

A final consideration when accessing federal funds is that a local match in funding is usually required. The ratio is usually an 80/20 split, meaning for every 80 dollars of funding provided by the federal government; 20 dollars of funding from non-federal sources would be required. The potential sources for these matching dollars are discussed in the Regional and Local Funding section of this report.

MAP-21

Moving Ahead for Progress in the 21st Century is the most recent federal transportation funding authorization, which replaced SAFETEA-LU. Much of the funding allocated under MAP-21 is considered “formula funding” which means funding distributions are dictated by formula calculations, often based on population or existing transportation infrastructure. All “formula funds" under MAP-21 require the recipient to be a recognized public transit operator. The SMSSV project would need to partner with an existing recipient of formula funds. There are two MAP-21 programs, new starts and small starts, that are specifically designed to implement new transportation infrastructure investments. The new starts program is intended for projects requiring over $250 million in funding. This program would not apply to the trial project of the SMSSV. The small starts program is designed to fund projects requiring under $250 million in funding. A requirement of the small starts program is identifying the public entity that would be the grant recipient. The SMSSV project would need to partner with an existing transit operator, likely the Santa Clara Valley Transportation Authority (VTA), to access this funding source. Another consideration for this funding source is the existing level of demand. The funding needs for projects that score well on the small starts criteria set forth in the legislation exceeds the level of available funding. This results in almost a de-facto waiting list for funding even for the highest scoring projects.

All of the specific rules governing the administration of MAP-21 funds have not been determined and a number are currently under development. Pending the outcome of these rules, the SMSSV project could be eligible for other programs. The requirement that the recipient be a recognized public transit operator would likely apply under all conditions.

Regional and Local Funding

The San Francisco Bay Area includes one of the most diverse regional portfolios of transportation infrastructure in the country. This portfolio includes light rail systems in San Francisco and San Jose, BART, Caltrain, Golden Gate Bridge, Bay Bridge, Cable Cars, and even ferries to complement motor vehicle infrastructure. To support the financial needs of this infrastructure, a number of regional and local funding sources have been utilized. These are discussed below.

Vehicle License Fee

Each year the millions of registered vehicles in the Bay Area receive new car tabs. A majority of this registration fee is dedicated to automobile purposes, such as road repair and rehabilitation. However, up to a 0.65 percent fee is currently levied to fund local transportation investments. Most regions in California have fully utilized this funding mechanism and implementation of an additional fee would likely require legislation at the state level. Legislation to raise the fee to two percent is currently under development. Although collection of these funds would require voter approval, many municipalities see this as an opportunity to raise critically needed transportation funds. The SMSSV project could partner with an existing public transit agency, or with the City of Sunnyvale, to explore the opportunity to access this funding source.

Sales Tax Measures

Most major transportation investments have been at least partially funded at the local level using sales tax measures. This funding mechanism allows for bonding and accumulation of debt without which the large expenditures required during construction of transportation infrastructure would be extremely difficult to make. The SMSSV project would likely only require a relatively small increase in sales tax to fund the trial. This funding source would require a coordinated public campaign within the City of Sunnyvale, and likely multiple political “champions” who would be the public face of the tax measure and associated trial project. This is a viable source for the SMSSV project, but would require additional political considerations that are not within the scope of this report.

Development Related Fees

Development related fees are a promising funding source for the SMSSV project. The specific structures of these fees vary dramatically and are usually designed to be context specific. Generally, a fee or tax on development is applied to a specific geography that directly benefits from the transportation infrastructure investments being made. These fees are then used to pay down the debt amassed during construction of the infrastructure. Another approach is to levy fees on specific types of development, such as buildings above a certain height or residential density, however this approach can result in variable levels of fees actually being collected, making any debt accumulation a much riskier proposition. In either case, implementation of any fee structure requires some level of municipal government coordination and usually a vote by those affected by the fee, or the larger municipal body.

Parking Revenue

Although not generally considered a major transportation funding source. The use of public space for storage of privately owned automobile has the potential to generate significant amounts of funding in urban environments. Adjustment of parking rates has been a politically charged subject, but should not be overlooked. Accessing this revenue source would require coordination with the City of Sunnyvale and the potential amount of funds that could be raised should also be examined.

Public-Private Partnerships

Public-Private Partnerships (PPP) provide one of the most viable funding sources for the SMSSV project. Similar to development fees, the scope and structure of PPPs vary and are almost always unique to the specific context in which they are applied. For the SMSSV project three general approaches to PPPs are development credits, media or energy partners, or Transit Oriented Development at a system wide scale.

Development credits would provide incentives for developers to support the SMSSV project by providing space for a station or areas for the ATN guide way to be located. Landowners would then be allowed to increase the size or density of the development beyond what is allowed under normal use. This would also benefit the ATN because it would concentrate the commercial or residential uses in areas adjacent the ATN.

The solar power and automated technology of the ATN opens opportunities to partner with media or energy companies. Solar panel manufacturers may see the SMSSV project as opportunity to widen the market for their products and media outlets may be attracted to a transportation system that embraces technology and features modern media elements in the stations or even the pod cars.

Finally, construction of fixed guide way transportation was used as a method to develop real estate in the 19th and early 20th centuries in the United States. Property owners along the Mathilda Corridor would all likely benefit from an additional transportation option. This increase in accessibility would result in increased property values and likely demand for space in the Mathilda Corridor. Bringing together property owners could result in development driven support, both politically and financially, for the SMSSV project.

Each PPP presents unique opportunities. These partnerships are not mutually exclusive and would likely work in conjunction, rather than against one another. Public-Private Partnerships are a viable funding source for the SMSSV project and have essentially no limitations on what is possible.

Competitive Grants

A number of competitive grant programs exist that could be applicable to the SMSSV project. These include both federal and regional grants. Nearly all sources are seen as highly competitive but the unique technology of the SMSSV project could be an asset in many cases and separate the project from its competitors.

Transportation Investment Generating Economic Recovery (TIGER)

The Transportation Investment Generating Economic Recovery (TIGER) grant program was developed to fund projects that would boost economic activity. There are separate urban and rural criteria, but generally the program funds innovative projects with multiple project sponsors that combine elements of transportation, land use, economic activity, readiness, environmental sustainability and livability. Projects should be of national or regional significance, which would qualify the SMSSV project. Although most recipients of this grant have been identified as regional priorities with the support from multiple jurisdictions, this is not necessarily a requirement. While the TIGER program generally distributes award amounts between $10-20 million, these funds are usually only a small portion of the total project funding. The TIGER program also requires awarded project be ready to begin obligating the awarded funds within 18 months, which generally requires the project to be environmentally cleared when submitting an application. Although this is a viable source for funding the SMSSV project, a number of hurdles would need to be cleared before a competitive TIGER application could be submitted.

Cap and Trade

California's Global Warming Solutions Act (AB 32) established a Cap-and-Trade Program. This program is expected to generate millions of dollars that will be re-invested across numerous business sectors to reduce the green house gas emissions of the State of California. While the specific amounts and uses of these funds have not been fully determined, a portion of these funds would likely be invested in green house gas reducing transportation infrastructure. The solar energy used to power the SMSSV project would obviously lend itself to any program promoting the use of clean transportation modes. Any discussion of the eligibility of the SMSSV project, level of funding, or criteria used to determine funding would somewhat premature at this point, but further investigation is warranted as the rules and regulations surround AB 32 continue to develop.

Other Competitive Grants

A number of additional competitive grants exist for which the SMSSV project may be a competitive candidate. These include the Transportation Fund for Clean Air (TFCA), Caltrans Planning Grants, and the One Bay Area Grant (OBAG) among many others. Each of these grants likely require some level of partnership with existing public transit operators or local governments. The level of potential funding and competitiveness varies by grant. As the SMSSV project becomes more clearly defined and gains project proponents these regional and local competitive grants should be further examined as potential funding sources.

Conclusions and Next Steps

The transportation funding landscape can be a difficult terrain to navigate. The number of potential funding sources can be daunting. In reviewing the current federal, regional and local, public-private partnership, and competitive grant opportunities a number of conclusions and recommendations can be made.

Federal funds are better suited for expansion of an existing ATN, rather than implementation of a new system. That does not mean that the SMSSV project would not be eligible under all federal programs, but the current structure of these programs favors established transit operators and modes. The SMSSV project could partner with an existing transit operator or municipal government, but this may be difficult and most public agencies are likely hesitant to take on additional responsibility without some level of guaranteed funding.

Regional and local funding sources are better suited for the SMSSV project. Although most sources require some level of either voter or political body approval, the level of flexibility of these funds is much greater compared to federal sources. A major component of the viability of any regional or local funding is the level of political support for the SMSSV project.

Public-Private Partnerships provide one of the most viable funding opportunities for the SMSSV project. Because each partnership is custom developed the unique nature of the SMSSV project would not be a hindrance. The level of involvement of public agencies and municipal bodies is minimized under this approach, although it is not eliminated. One consideration is the involvement of private funders and for-profit companies may disqualify the SMSSV project from other funding sources.

The number of competitive transportation grants is vast. Many grants have very specific requirements that the SMSSV project may or may not meet. These sources should be further examined as the SMSSV project develops, but would likely represent only a small portion of the total funding source for the SMSSV project.

The potential funding sources outlined here is not a comprehensive list, but represent the most likely and viable sources known at this time. While none of the sources listed here should be eliminated from further consideration for the funding of the SMSSV project, the most viable funding source at this time is a Public-Private Partnership. To explore PPP opportunities, meetings and outreach with business and community leaders should be held. Developing a list of interested parties would be a first step, after which details of the SMSSV project could be discussed. The City of Sunnyvale would be a primary partner in any agreement and should be kept aware of any and all developments. Finally, development of a PPP is a highly complex agreement and would require expertise from a number of fields including urban planning, construction, law, and real estate, among others. As the SMSSV project is further refined and potential partners become more committed, individuals with these areas of expertise should be brought onto the SMSSV team and the funding sources outlined here reexamined for applicability.

Glossary

AC	Alternating Current
ADA	American's with Disabilities Act (USA)
APC	Autonomous Pod Controller
APM	Automated People Mover
ASC	American Solar Challenge
ATN	Automated Transit Network
BART	Bay Area Rapid Transit
CEQA	California Environmental Quality Act
CES	Center for Economic Studies
CNU	Congress of New Urbanism
CPUC	California Public Utilities Commission
CTC	California Transportation Commission
DC	Direct Current
DDA	Disability Discrimination Act (UK)
DOT	Department of Transportation
DOT	Department of Transportation
Du	Dwelling Units
Du/A	Dwelling Units / Acre
EIR	Environmental Impact Report
FEA	Finite Element Analysis
FTA	Federal Transit Authority
GRT	Group Rapid Transit
HVAC	Heating, ventilation, air-conditioning

INIST	The International Institute of Sustainable Transportation
Ju	Job Units
Ju/A	Job Units / Acre
LCD	Liquid Crystal Display
LED	Light Emitting Diode
LIM	Linear Induction Motor
LSM	Linear Synchronous Motor
maglev	Magnetic Levitation
PRT	Personal Rapid Transit
RFI	Request for Information
SAM	System Advisory Model
SAN	Storage Area Network
SMSSV	Sustainable Mobility Solution for Silicon Valley
SQL	Sequential Query Language
SVIC	Silicon Valley Innovation Challenge
UML	Universal Modeling Language
USDOT	United States Department of Transportation
VTA	Santa Clara Valley Transportation Authority