# SuperWay

A Solar Powered Automated Transportation System

San José State University

College of Business

College of Engineering

College of Applied Sciences and Arts

December 12, 2012

Business: Christian Jorgensen and Stephanie Tucker

Engineering: Bryan Burlingame, Andrew Davis, Thinh Duong, Medi Gouta, Samuel Gutierrez, Simone Jackson, Grant Kleinman, Kevin Kwong, Andrew Lee, Cynthia Lee, Jonathan Lee, John Leone, Tim Meacham, Uriel Rosas, Jonathan Ross

Planning: Jonathan Kibrick

Volunteers: Edward Lam, Lasiz Lam, Tuwin Lam, Ariunaa Leone

# Abstract

The SuperWay is a proposed Personal Rapid Transit system design for the city of San José, California. The system is an alternative to public transportation that is less expensive both to create and to maintain than current modes of transportation, reduces wait and travel times, and uses existing transit corridors. Additionally, it is more environmentally sound, as it is 100% net solar powered.

The system was divided in to six engineering components of cabin, propulsion, structure and guide way, solar energy, control systems, and station design. Each component was analyzed separately in order to determine the best design. The design process included four stages: research of the state of the art of the component being examined, specifications of the component detailing exactly what constraints it must abide by, technology selection to determine the optimal model for a design, and lastly, the preliminary designs of the components to be included in the system. The route and urban planning was also considered, which included corridor selection and land use entitlements.

The research and calculations determined the system should include a cab that fits six adults and has approximate dimensions of 180”x75”x84”. The propulsion method to be used is a linear induction motor (LIM) with intent to achieve a speed of 45 miles per hour. The cabin is to be suspended from the guide way with a ground clearance of at least 14 feet. Columns of the structure are to be made of A574 grade 50 steel and spaced 40-50’ apart. The guide way is to be a Pratt truss. Stations are to include angled-birth tracks, with options for sub-lines for higher traffic areas. Optimal 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 will utilize a hybrid centralized system which holds supervisory authority over semi-autonomous subsystems.

# Table of Contents

# Chapter 1: Executive Summary

Transit in the United States of America is quickly becoming unsustainable as the infrastructure costs are growing dramatically. Also, the population and the number of drivers in the U.S are on the rise. As a result, traffic congestion is causing commute times to reach unacceptable levels. There are currently no other appealing alternatives in the Silicon Valley.

The Sustainable Mobility Solution for Silicon Valley, a team of Business, Urban Planning, Software, Mechanical, and Computer Engineering students at San José state, has worked for the better part of four months to begin specifying a fully functional automated transit network (ATN) for Silicon Valley based on personal rapid transit. Significant interest was shown from the city of Mountain View, city of San José, and Santa Clara County.

Passenger safety is the most important concern throughout this process. The Cabin design is ADA compliant and seeks to provide a comfortable and safe environment. Various preliminary design concepts are included in this report for both the interior (cabin) and exterior of the pod. The design team has decided on a suspended PRT system as the concept for the SuperWay. It has also been decided that the SuperWay will be 100% solar powered.

For practical reasons, pods will necessarily go to the places where people live, work, play or shop. A transit supportive land use metric is used in this report to identify and prioritize routes and corridors for urban development.

This system will be designed so the individual pieces can be prefabricated at one location, then carried and assembled at the construction site. For maximum efficiency, the station will allow pods to bypass other pods at the station which will also decrease travel time and improve customer service. When it comes to propulsion, linear induction motors will be used due to their expected low maintenance costs and environmental acceptability.

The system will be capable of moderate speeds (45 MPH), and solar panels on the top of the guide way will optimize energy production. SAM simulations were done on various solar cell technologies to see how much energy each would produce. It was concluded that storage will be needed for the vehicle in case of power failure.

From a software perspective, the ultimate architecture will utilize a Master Contoller monitoring and overseeing a large set of distributed semi-autonomous subsystems. There will be an Autonomous Pod Control which will safely move the pod down the track between stations and through merge points, a Merger Controller which will coordinates merge railway intersection through monitoring and negotiation with the incoming pods, and a Master Controller which will act as the central authority for the entire system and handles alerts and routing requests from reservation system or administrator. Finally, the control system will be complemented by a Reservation System which will allow passengers to purchase tickets through terminals and web accessible platforms.

# 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: Comparison in Inflation between Road-Miles and the General Economy (1961-2010) (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: Growth of Road Miles by Population and Vehicle Miles Traveled from 1961 to 2010 (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 it 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: Inflation by Energy Type (1999-2010) (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). 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.

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.

# 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 guide ways which exhibit the following characteristics:

1. Automatically controlled vehicles which travel to their destination without human intervention (except in case of catastrophic failure, of course)
2. On-demand service. A vehicle arrives when summoned, not upon 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) (Carnegie, Voorhees, & Hoffman, 2007)
5. A discrete guide way, 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:

- Small vehicles targeting one to six riders.
- Vehicles able to function around reasonably tight turns.
- Light weight vehicles to minimize energy and guide way 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:

- 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 guide ways. Elevated guide ways 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 a market for 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 were 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.

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, 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 automated system at the San José International Airport. The proposed system would connect the airport with the existing VTA light rail system and Cal-Train. It was estimated in the report that such an Automated People Mover (APM) would cost the city $640 million for the two-mile system—due to the high cost the APM was rejected.

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. 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. (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

The Solar Sky Ways Challenge is a multi-disciplinary competition created and judged by The International Institute of Sustainable Transportation (INIST) challenging teams of university students to propose and prove the viability of a solar-powered ATN. (INIST, 2012) By providing a $5,000 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, 2012-2013 document, 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 guide ways 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 to the Solar Skyways Challenge. The Solar Skyways Challenge is a brand new international challenge which will compare and contrast the different pod car systems submitted and select the most promising innovations to support the advancement of society.

These two goals ultimately lead into the need for a full definition of specifications and constraints to the SMSSV PRT system. Two examples of constraints and specifications are that the power source will be utilizing only solar power, and the pod car will be suspended. Establishing these constraints and specifications will make it easier for this group as it moves forward in the system design process.

This task would be fairly daunting if it were not for significant research and analysis on previous ATN systems. Instead of reinventing already implemented technology, this team will analyze competing technologies' pros and cons in order to select the components most appropriate for this system.

Determining the feasibility of personal rapid transit and establishing the system in Silicon Valley must be performed for financial reasons. The project must be financially feasible especially when compared to past and present systems.

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.

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

## 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

## Structures/Guideway

- Design a structure to safely support the pods
- Plan for exceptions such as earthquakes and other potential disasters
- Design a guideway to be integrated with the structure which pods can run on
- Consider aesthetics

## 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 guide ways system
- Locate five largest potential trip generators and the closest existing major transit hubs and nodes

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

## Cabin Design

### Beamways

A master's student in Sweden developed the design shown in below for his master thesis. The cabin design shown was designed for a suspended system. This 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. 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's 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.

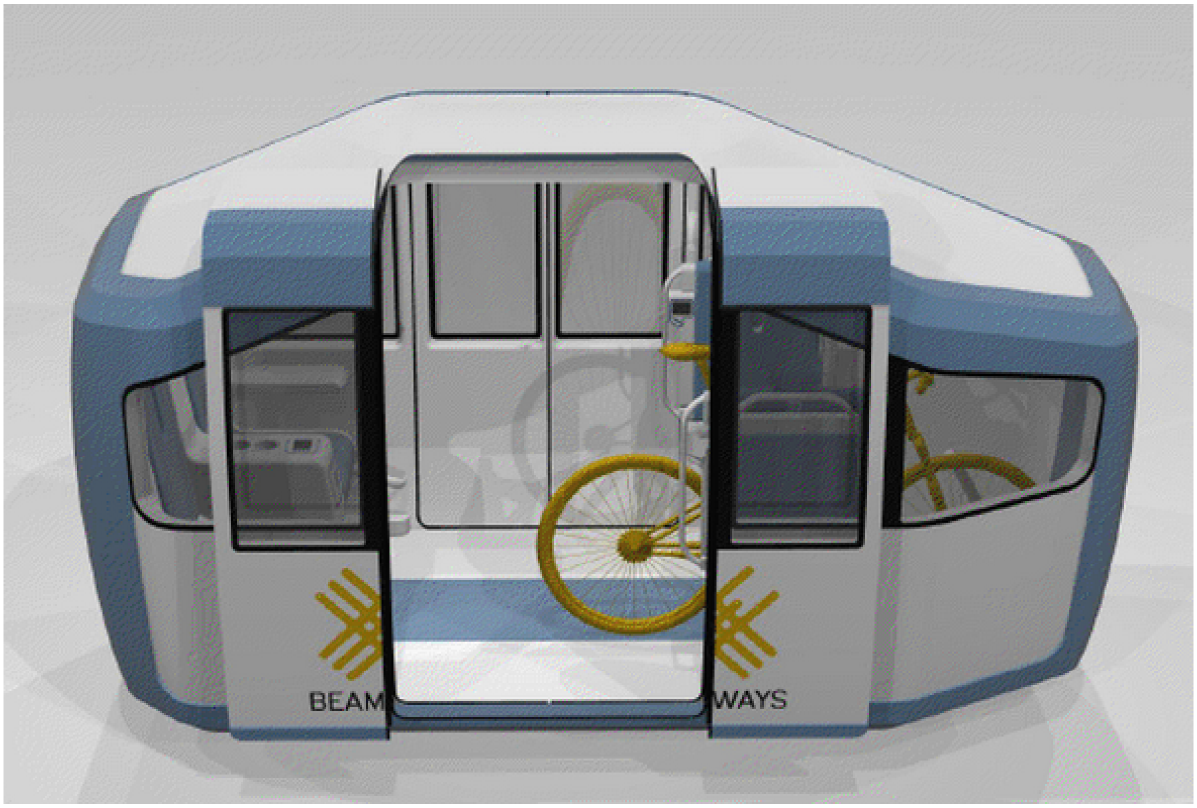



**Figure 4: Beamways Cabin Design (Beamways, 2012).**

## 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 6 seated passengers.

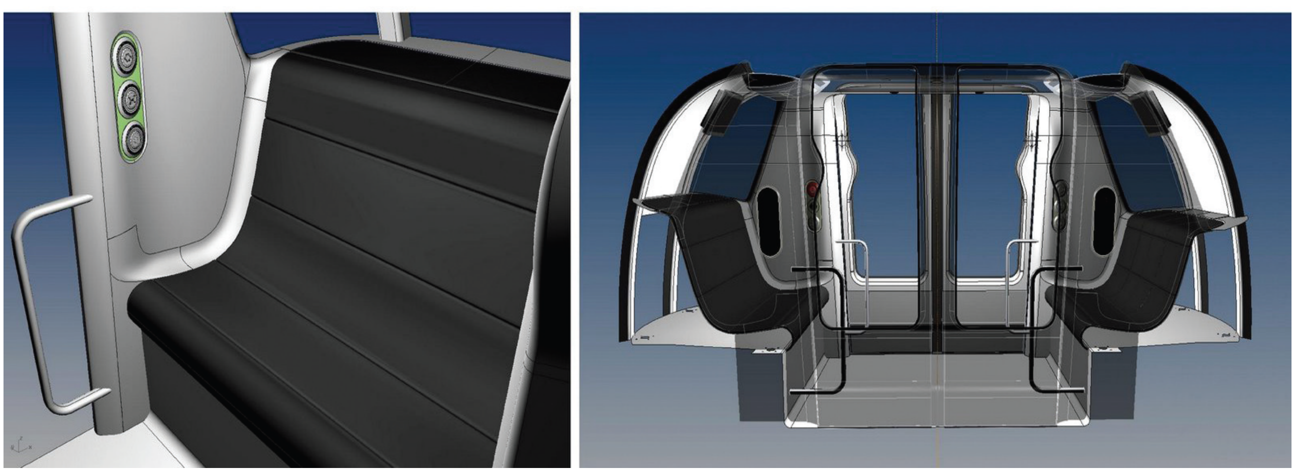


**Figure 5: The interior layout of Ultra's cabin design features bench seats which face one another. Retrieved from http://www.ultraglobalprt.com/wp-content/uploads/2011/08/PDF_Vehicle-features.pdf**

The cabin weighs 850 kg (approximately 1875 lbs) when empty but its maximum mass at capacity is approximately 1300 kg (approximately 2886 lbs). The cabin measures with a vehicle length of 3.7 m, 1.47m 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 as such complies with the United Kingdom's Disability Discrimination Act (DDA) and it also complies with the United State's ADA requirements. The double door opening is about 0.9 m (3 ft) wide thus easily accommodating wheelchairs, bicycles and large cargo.

The interior is also illuminated to allow passengers to enjoy reading; contains a liquid crystal display (LCD) to relay relevant trip information to occupants; and provides heating, ventilation, and air conditioning to provide a comfortable ride. Additional notable features of the vehicle include 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.

## H-bahn

H-Bahn is a suspended 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 6: The H-bahn cabin features 16 seats which can accommodate multiple sized parties and the spacious layout allows for standing passengers. Retrieved from http://www.h-bahn.info/en/technology/vehicles.php.**

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).

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

The Vectus system is a concept that was developed in Korea. Its compact 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 provide a comfortable and luxurious trip to the passenger and 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 3 layouts for the interior, the most basic of which is shown below.


**Figure 7: : Vectus Cabin Design. Retrieved from http://www.vectusprt.com/system/vehicle.php**

# Propulsion

Selection of the propulsion system type and its subsequent design specifications were based upon previously established systems and the analysis of those systems. The two primary options for a propulsions system for personal rapid transit (also known as pod cars) are rotary motors or linear induction motors. Although magnetic levitation (maglev) exists for mass public transit (i.e. Japan's high speed bullet train), it is an unfeasible propulsion system due to this projects 100% solar power constraint. In addition, magnetic levitation, in the form of linear synchronous motors, is far more expensive to implement and due to the scope of this project, will not be considered. However, maglev will still be discussed briefly below. Conforming to the standard of public transportation, all proposed or currently available pod car propulsion systems operate with electricity as its primary fuel source. Therefore, all linear or rotary motor propulsion systems will be powered by electricity. The conventional rotary motor propulsion system operates on a well-known and established technological database. Rotary motors 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, examples such as BART or traditional cars, there are alternative propulsion systems that are becoming more popular. An example would be the linear induction motor. These were more recently developed, with the first feasible linear induction motor design by early 20th century inventor Alfred Zehden of Frankfurt-am-Main ( U.S PATENT 782,312 HTTP://WWW.GOOGLE.COM/PATENTS/US782312). For ease of understanding, examples of rotary and linear motors will be provided by the following analysis of the ULTra and Vectus systems in today's state-of-the-art technology review.

The ULTra system located at London's Heathrow Airport, utilizes the conventional rotary motor propulsion system. 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 relatively inexpensive when compared to a linear induction motor system. While ULTra is a convenient and reliable system, it fails at several key features. The ULTra system cruises below 25 miles per hour, which decreases the amount of passengers per hour, and requires significant maintenance. Maintenance for the ULTra system includes, replacing wheels, motors, batteries and various components that wear down; along with tending to the concrete guide way and positioning sensors. These costs are not included in the capital investment, but will surface over time (Costs summary, n.d.).

**Figure 8: ULTra PRT system in London, ultilizing rotary motors http://www.ultraprt.net/cms/uk/ BAA_prt_image_03smaller.jpg**

2GetThere's rotary motor based propulsion system (currently installed in a test section of Masdar's infrastructure) proves that a rotary propulsion system works and can be used, but implementation is key to integration. The Masdar PRT initiative required the entire city's infrastructure to be modified in order to accommodate these autonomous vehicles, something that increased costs by several orders of magnitude (Carlisle, 2010).

The WVU PRT system (currently operating in Morgantown, West Virginia) is another example of a tried, true, but inefficient form of public transportation. It utilizes the standard rotary propulsion system common in other forms of personal rapid transit. However, the WVU PRT has a higher capacity and only supports a small corridor of transportation. An extremely important factor to recognize in the WVU PRT's case is its estimated initial cost of approximately $30 million dollars to its actual $150 million dollar cost due to land use and other governmental fees. This reinforces the notion that minor differences between rotary and linear induction motor costs to be a negligible factor in technology preferential and selection (Booth, 2007).

Another personal rapid transit system utilizing rotary propulsion is the CabinTaxi system designed and prototyped in Germany. Yet another example of cost being a negligible consideration in propulsion type design, the CabinTaxi's rotary propulsion system was denied funding costs due to lack of support. This drives home the fact that the cost of a propulsion system is one of the least important factors of the personal rapid transit system as a whole (Burger, 2012).

The Vectus system, located in South Korea, currently has several full scale prototypes that demonstrate full functionality with linear induction motors. The propulsion systems on the Vectus pod cars consist of an aluminum conductor located on the bogey, while the linear induction motors (LIM's) are housed inside the track. The LIM's produce an eddy current that reacts with the conductor on the pod cars, resulting in a forward propulsive field (Gow, 2009). The main advantage of placing the LIM's throughout the track is to reduce weight and simplify the pod car. With a lighter pod car, less energy is used during travel.

**Figure 9: Vectus PRT system, utilizing LIM's embedded in the track http://www.universaldesignstyle.com/wp-content/uploads/2012/07/Station_01_1_3.jpg**

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 PRT system constructed a partial prototype with full functionality, proving the application and validity of linear induction motor propulsion systems (Skyweb express feasibility study, 2007).

Currently, there are no functional personal rapid transit systems that exist with the implementation of magnetic levitation; however, there are several heavy rail systems. Heavy rail systems can utilize magnetic levitation more easily due to fewer destination points. When a network of personal pod cars is travelling on one track, controls and power management become more difficult. Also, due to the high cost of the guide way and the large amount of coils needed, the ever expanding network will continue to require many investors.

One popular proposed PRT system which features a new form of magnetic levitation is SkyTran, by UniModal. Skytran has developed a technology that has low power requirements and plenty of thrust capability. They are aided by the fact that the cabin is meant for two people, making each pod car very light (Marlaire, 2009). However, with no fully functional, this propulsion system faces extreme discrimination due to its new technology and untested principals.

# Structure

Several suspended transit networks were studied in detail in terms of their structures/guide way in order to understand the technology that currently exist or is under development/study.

## Cabintaxi

Cabintaxi PRT system utilized a double track guide way that allowed 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 consist of a box girder, completely encapsulating the bogie, and provide guidance and support for vehicles.

## Cabinlift

Cabinlift is an automated PRT system, utilizing the experiences gained from Cabintaxi. 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.

## SIPEM(Siemens People Mover System) H-Bahn

H-Bahn is a suspended, automated monorail system developed by Siemens, currently in operation in Dortmund and Düsseldorf, Germany. Their guide way consist 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. This box girder design makes the track more resistant to torsional and bending stresses. Each cabin vehicle requires two motorized bogies. The girder completely encapsulates the bogies so that they would be protected from the elements. All components of the structure and guide way are ready-made in factory and assembled on location. This provides a major advantage for this system, an advantage shared with SkyTrain.  H-Bahnis currently still in operation.

## 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, see below, which allows vehicles to switch from rail to rail with ease and has the capability to lower vehicles down to street level.

**Figure 10: MISTER PRT truss-rail concept**

## 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 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

With the exception of a handful of operating PRT systems, 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 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. It has been proven that off-line stations decrease travel time because the vehicle does not impede the mainline, allowing other vehicles to keep traveling to their destination. Off-line stations also decrease travel time because the vehicles do not decelerate until they are off the mainline and are traveling at full speed when merging back to the mainline.

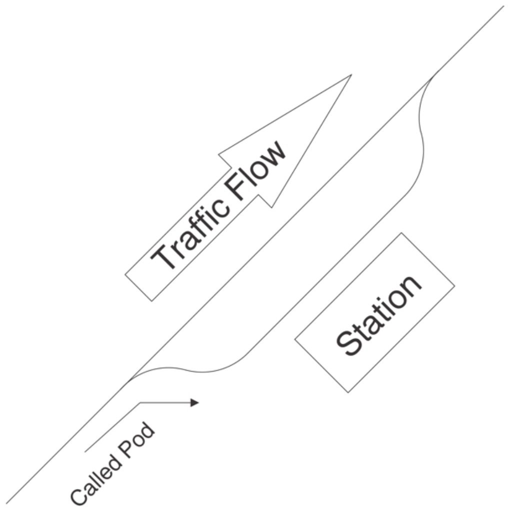



**Figure 11: Representation of offline station.**

## Linear Station

A linear station design is the most commonly used station design to date. 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-Birth 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 station, 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 congestion build up in the station and a decrease in the quality of customer service. An angled-birth station, as shown below, eliminates this issue. Instead of vehicles lining up behind each other, they pull into births 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. PRT systems that currently use this type of station set up at 2gether in Masdar and Ultra at Heathrow Airport.

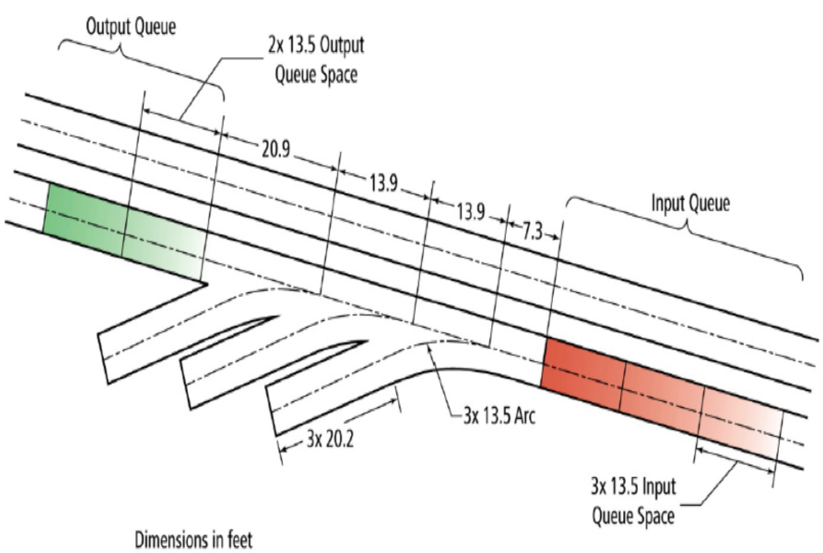



**Figure 12: Angle Birth Station Design (Paige, 2012).**

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

# Solar

As of 2012, there are no solar-powered ATN systems currently constructed or 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. 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 starting to become a reality. However, it is equally clear from the illustration that the design of the vehicle still has a ways to go before it is something the consumer can use.

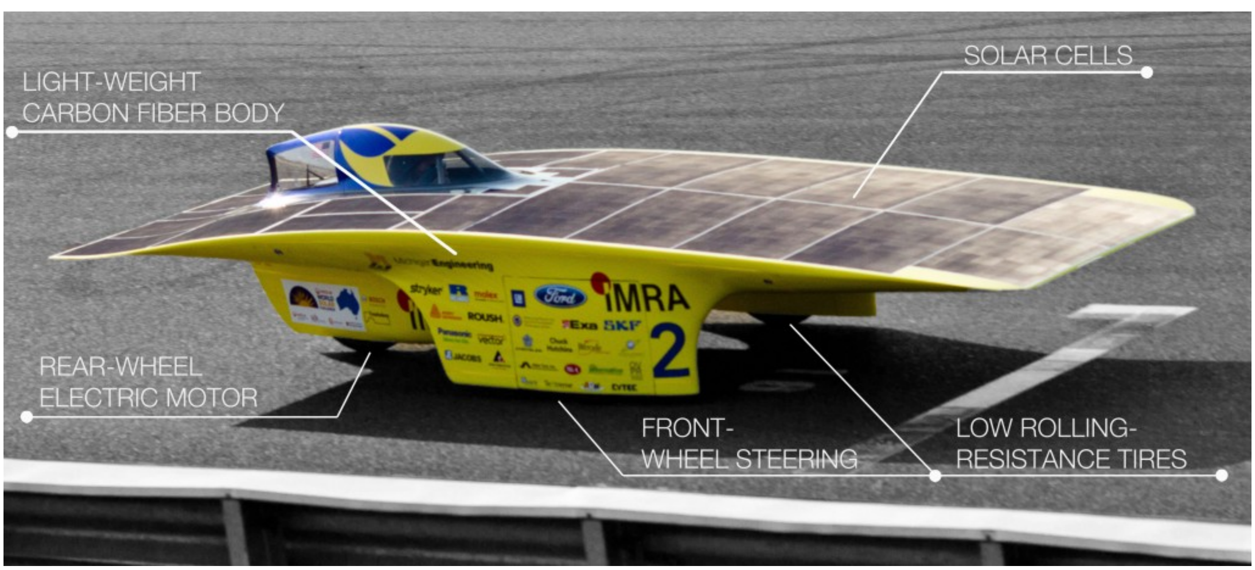



**Figure 13: Quantum, University of Michigan's Solar Powered Car (Source: http://solarcar.engin.umich.edu/the-car/)**

The solar car has one significant drawback that ATN does not – it must contain all solar cells within the space of the vehicle itself. ATN has both the flexibility and financial advantage of being able to use miles of track to support solar cells necessary to provide for the energy requirements of its vehicles. This allows the cars to be significantly larger and heavier, and, as a result, more spacious and suitable for several people. 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 a report by Beamways [12]. As a result, they are likely to be the forerunners when looking at solar-powered ATNs. 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 tilt is briefly addressed, but the problem is not solved. 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. As of yet, this problem does not appear to have a published solution within the given constraints.

# 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 SVSSM ATN System

## Cabin

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 be perfectly intact and the passengers unharmed.

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 compliancy is a major requirement in order for this system to be established. In Section §1192.53a of the Access Board Transportation Vehicle Accessibility Guidelines, 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 (The engineering toolbox, 2011) and the acceleration speed (Pemberton, 2012) were estimated for this system type. An acceleration of 1.125 meters per second squared is comfortable for passengers to experience. Using these variables, the maximum amount of thrust during acceleration and cruising was calculated. The final sizing of the motors will include the thrust along with the spacing of each motor and the specifications of the coils. By minimizing the size of the motors, the cost of the system and the power consumption will decrease. The result will be an actual power consumption calculation instead of an estimate from a previous design.

Rotary motors were not selected because they do not meet the goal of 50 miles per hour and quick braking. While rotary motors offer less power consumption, the braking system used to stop the pod car would have to consist of steel wheels and would be ineffective at low separation times between pod cars.

While magnetic levitation designs exist that use little energy and generate enough thrust, such as in Skytran, the technology has not yet been developed and tested enough to be certain about its capabilities.

**Table 1: Propulsion Design Specifications**

| Propulsion Design Specifications | Value | Units | BOE | Comments |
|---|---|---|---|---|
| total nominal forward thrust | TBD | N | A | See note 1* |
| total max forward thrust | TBD | N | A | See note 1* |
| nominal forward thrust | TBD | N/motor | A | See note 1* |
| max forward thrust | TBD | N/motor | A | See note 1* |
| motor spacing | TBD | meters | A | |
| number of coils per motor | TBD | 1 | A | |
| number of coil turns | 100 | 1 | A | Estimated |
| total acceleration thrust required | 7300 | N | A | |
| cruising thrust required | 2950 | N | A | |
| total acceleration power required | 15 | kW | A | to 10 MPH |
| cruising energy draw | 400 | Wh/mile | D | Estimated |
| trip energy draw | 700 | Wh/mile | D | Estimated |
| cruise speed | TBD | MPH | D | |
| max speed | 50 | MPH | D | |
| acceleration speed | 1.125 | m^2/s | D | |
| max acceleration | 5 | m^2/s | D | |
| air drag per passenger | 0.0601 1 | N | A | |
| vehicle drag | 0.13 | kN | A | |
| auxiliary power | 2200 | watts | A | HVAC, controls, lighting |
| road resistance | 0.0003 | X | A | |
| wheel diameter | 15 | inches | D | |
| bogey width | 30 | inches | D | |
| bogey height | 45.5 | inches | D | |
| bogey length | 48 | inches | D | |

1* Current calculations need revision as they do not account for the reflected resistance to the primary using the square of turns ratio found in the transformer theory.

# Station

Listed below are ADA requirements which must be meet for station design:

- 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. Research suggests that it's 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. Due to such parameters not being fully defined, the SMSVV 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. Some highlights from their study:

- Heating, ventilation, & 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.

It's important to note that there needs to be a study is based on that particular site, thus a one system fits all approach is not adequate. That does not imply that the team's findings cannot be used for the SMSVV. On the contrary, their results can be used to design a SMSVV that can use proper thermal management to reduce energy consumption.

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 [1]. To verify their results, the solar superteam in collaboration with the propulsion superteam used energy equations developed by J. Edward Anderson (a leader in PRT design) [4]. The main assumptions made in the energy equations are vehicle average speed (cruising speed), propulsion efficiency, and vehicle weight. The teams took a conservative approach in its assumption, and assumed a propulsion efficiency of 80%, 5,000 lb. vehicle, and an average speed of 18 mph. The reason for this conservative approach is to be able to design a power system that will meet the power demand for any unknown power requirements. Based on 6 passenger occupancy the energy consumption is 1632 kWh/day/mile.

**Table 2: Comparison of Energy Requirements Estimates per Mile of Guide way**

| | ATN Feasibility Evaluation Study | Swenson & Baertsch | Solar Superteam |
|---|---|---|---|
| kWh/mile/day | 1600 - 250 | 2440 | 1632 |

Based on the results, Swenson's & Baertsch's estimate is taken as the maximum energy requirement to design the SuperWay. This ensures that the solar power system is not undersized.

# Control Systems

The primary functionality of the system is outlined below. A key consideration in the designation of requirements for the system was safety and redundancy.

## Functional Requirements

1. The Control System shall have redundancy
2. The Control System shall have redundancy for all critical systems to ensure safety.
3. The Control System shall have no single point of failure that will bring down safety critical components.
4. The Control System shall prioritize all safety measures in the event of a fire, earthquake, or pod failure.
5. The Control System shall implement a quasi-synchronous system in which intelligence is distributed throughout the hierarchy of the system.
6. The Control System shall implement system wide health state awareness in major systems
7. The Control System sub-systems shall run independently from each other and rely on shared intelligence
8. The Control System shall implement a primary controller that will act as a central authority, however still have limited functionality without the central authority.
9. The Control System shall be able to deliver passengers to nearest station during a critical failure of Master Controller.

10. The Control System shall implement security and encryption along all communication mediums between sub-systems
11. The Control System shall be capable of adding additional stations without major changes and programming
12. The Control System shall be highly scalable for large geographical areas
13. The Control System shall support high traffic demands during peak hours
14. The Control System shall have the capacity to support enough pods for the populated area
15. The Control System shall monitor traffic and predict traffic patterns for reporting and demand prediction
16. The Control System shall be able to route cars to all available stations

## Non-Functional Requirements

The Control System shall have at least a system uptime of 99.9

# Chapter 7: Technology Selection

## Cabin

In order to be ADA compliant and provide a comfortable and safe environment, the preliminary design has been implemented with some current safety requirements into the design. It is required by federal law that wheelchair users must be able to back his or her wheelchair up against a flat surface when the vehicle is in motion. Beamway developed a concept where the user would push a button in the pod to fold the bottom of the seats up, creating the needed flat surface. Providing this automated feature improves the quality of service for wheelchair users and will prevent future lawsuits from the user not being able to fold the chairs manually.

Vectus's HVAC and lighting systems were also chosen to be implemented into the preliminary design. The HVAC controls and lights are located in the center of the ceiling. A set up shown here allows the user to control the light and HVAC setting in the cab. All air needed for the system is fed into the HVAC unit directly, thus eliminating the need for ducting to the sides of the cabin and decreasing the weight of the pod. The location of the control also allows for easier access when maintenance is needed.

The unibody of the pod is to be made of an aluminum alloy due to the excellent structural stiffness to weight ratio. The pod must be both rigid and stiff so that any energy would not be loss due to any deflection in the unibody. Weight is an important factor, especially because this system is to be powered completely by solar power. Any additional weight translates to an additional need of energy to power and drive the pod.

Interior 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)

## 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. 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, this system will reach its top speed.

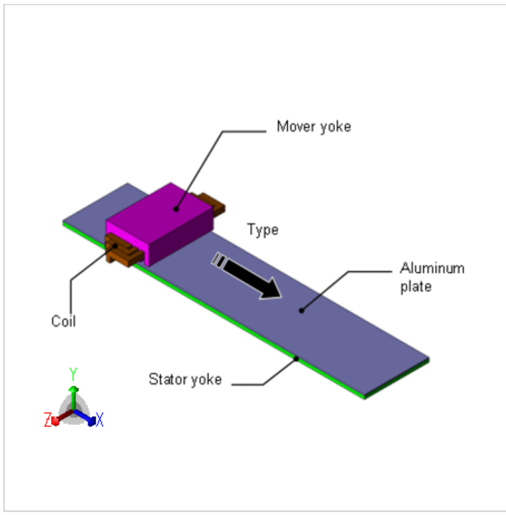



**Figure 15: Fundamentals of linear induction motors https://www.jmag-international.com/catalog/img/e104-1b.gif**

In order to create prolonged thrust, 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. A dynamic motor also utilizes a single-sided LIM (SLIM) design (Gastli), but now has a short primary motor over a long secondary conductor. 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 melt. Therefore, to increase the reliability and efficiency of the system, the track will carry the LIM's.

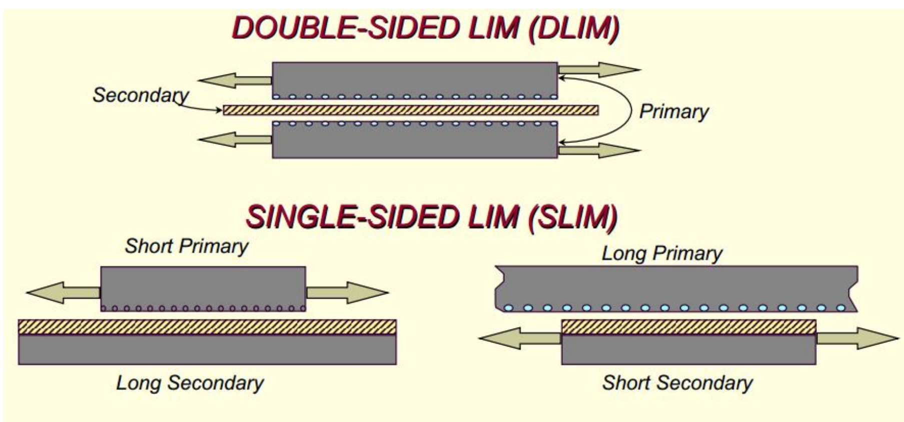



**Figure 16: DLIM versus SLIM http://emsa.gastli.net/Chapter8/Linear_Motors.pdf**

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, modern braking, such as disk or drum brakes can also be used to assist slowing the vehicle. Using a modern 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). 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). 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. While other systems require maintenance, like repairing and replacing electric motors and gearing, LIM systems do not need replacement, partly because the design of the motor has no moving parts and no permanent magnets (Desantis). With few moving parts, this motor will have 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 RPM the motor has. Electric motors have an optimal point at which they are most efficient. In order to reach higher speeds at the optimal point, a transmission is required. 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*).

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 non-conductive 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 5,000 pound pod car. Also, as a form of magnetic levitation, there is no simple solution to track switching.

# Structure

The design team has decided to use a suspended PRT system for the SuperWay concept. 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 guide way 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 designed so the individual pieces can be prefabricated at one location, and then 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 using cast-in-situ piles will be utilized.

# 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 17: Various solar panels were chosen based on their module efficiency.**

**Figure 18: 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 the top figure, 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). 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 28.8%, ultra light-weight and superior flexibility [6]. Further analysis of this technology will be investigated and will also be a top choice for the SuperWay.

It is important to know whether the system will be suspended or supported. 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 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 guide ways 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 Congress of New Urbanism (CNU) inspired developments, the densities for population and gross

[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.

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 4: 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.). |

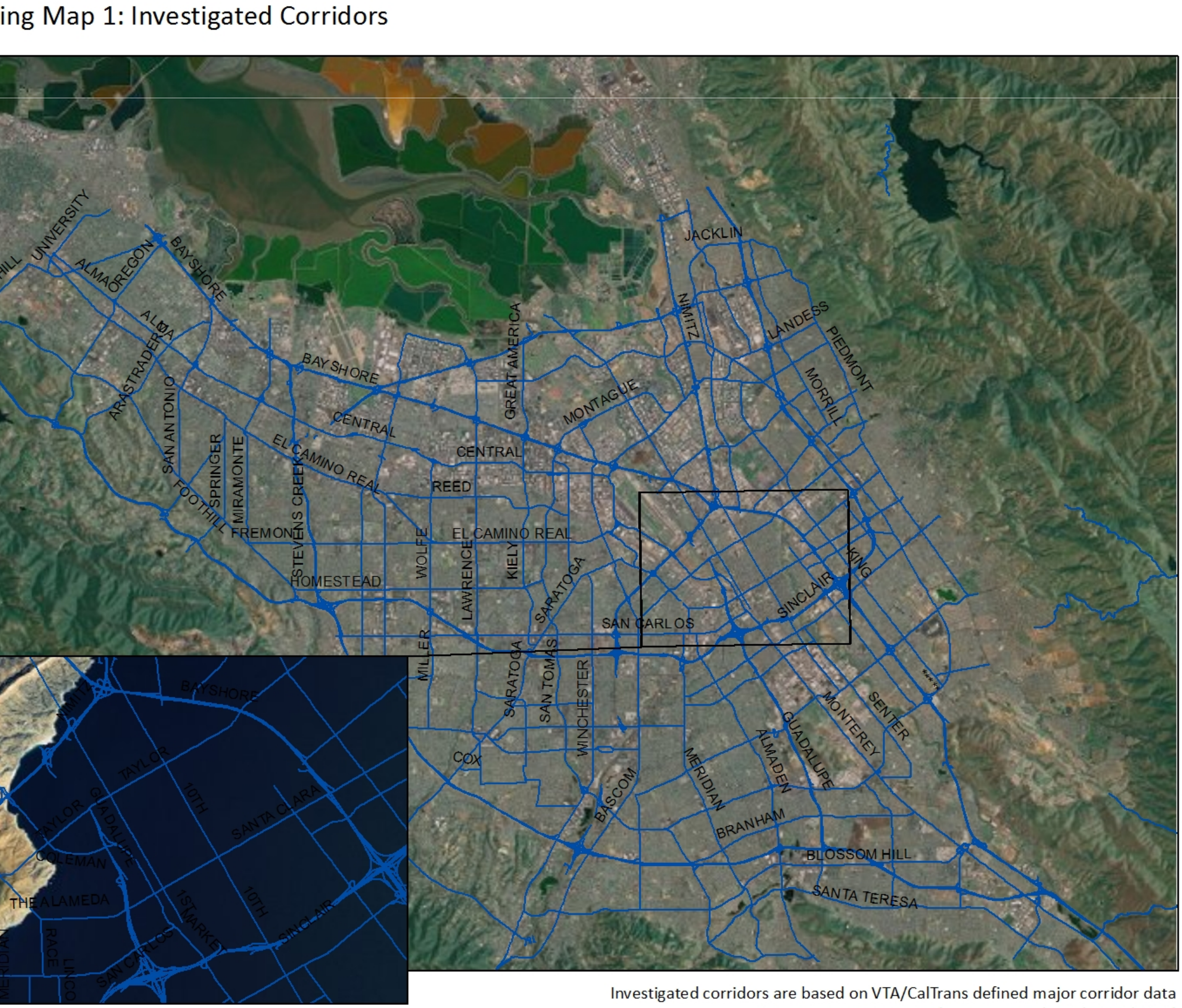
# Corridors for Consideration

### 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**.

**Figure 19: Planning Map 1**



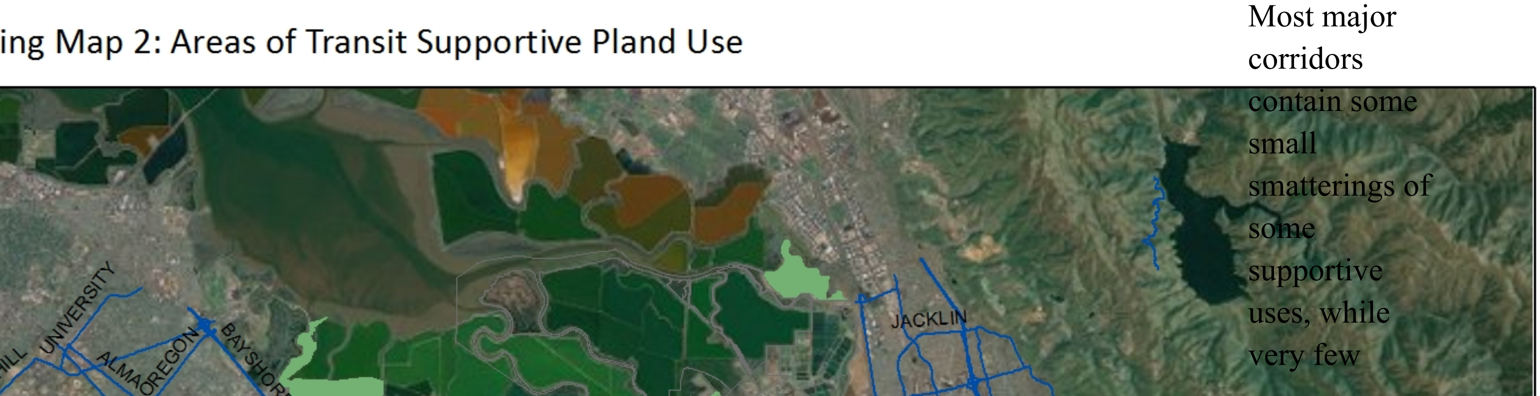

**Which Corridors have the most sportive land uses?**

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 20: Planning Map 2




Most major corridors contain some small smatterings of some supportive uses, while very few

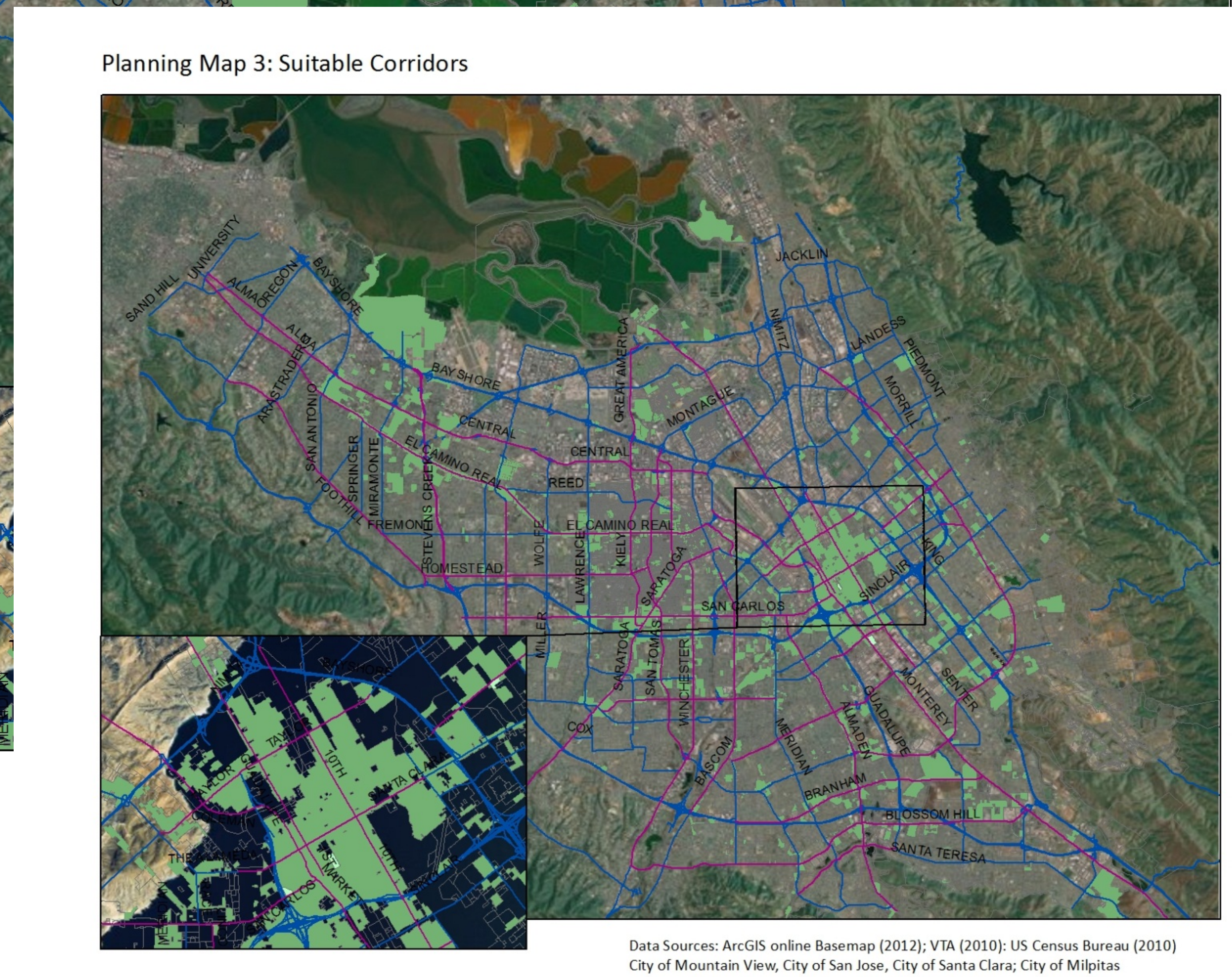



Figure 21: Planning Map 3

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.

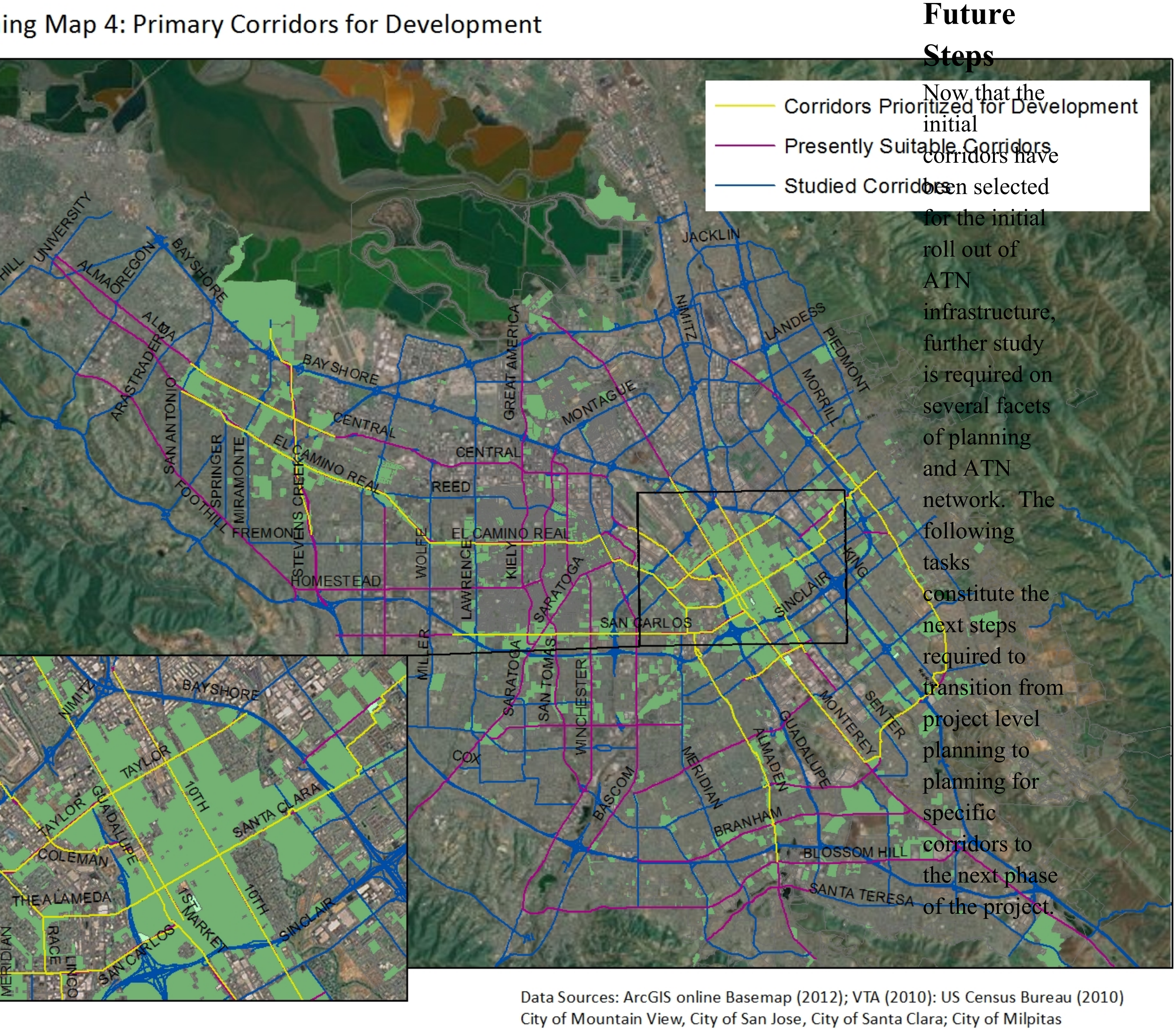
**Proposed Initial Corridors**

Once the most suitable corridors had been found, an initial set of sub corridors had to be selected 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 22: 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 23: 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 24.

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.

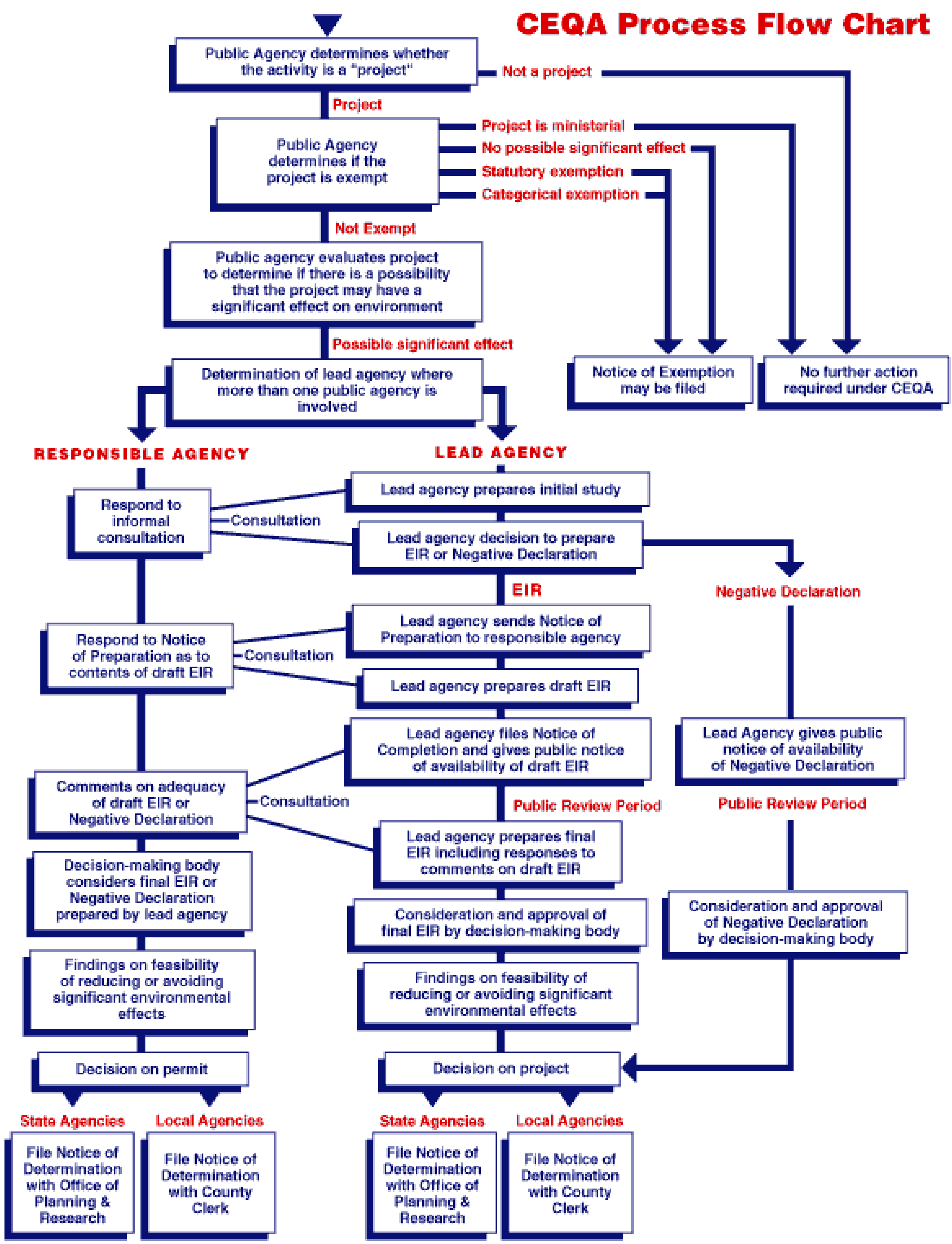



**Figure 24 The CEQA Process (California Environmental Resources Evaluation System, 2005)**

## 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

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: Preliminary Design

## Cabin

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

### Exterior

The general exterior shape of the pod has been influenced by both past and present shapes and designs. Starting with the nose(s) of the pod, aerodynamics was kept in mind. An aerodynamic nose minimizes drag and friction, allowing the pod 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 pod to cut through the moving air.

Instead of one pointed nose at one end, the pod 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. One of the advantages that this pod 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 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 blend smoothly into the main cabin section, which is approximately 96 inches long (exterior). The floor space inside the cabin section is longer at 110 inches long due to the fact that the floor also incorporates an extra 14 inches for the seats (**Figure 19**).

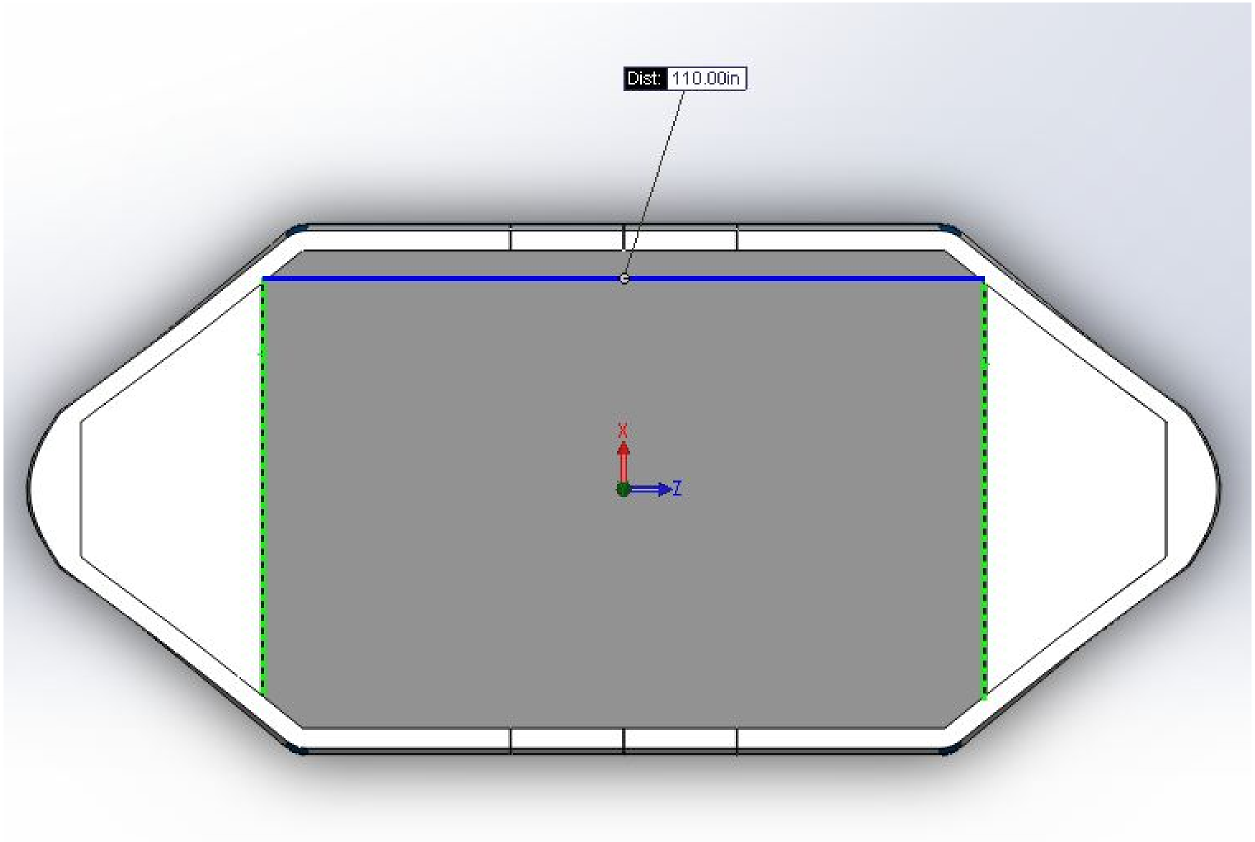



**Figure 25: Floor is 110 inches long**

The floor length was needed to be long 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 (Minnesota Department of Transportation, 2007). The length is definitely less than the 110 inches of floor space, but extra length is needed so that the bicycle rider can maneuver their bicycle easily.

Although the width of the exterior of the pod is 81 inches, the width of the interior cabin floor space is 75 inches (figure below) since the thickness of the shell is 3 inches. The floor width of the cabin was designed after sizing the seats.

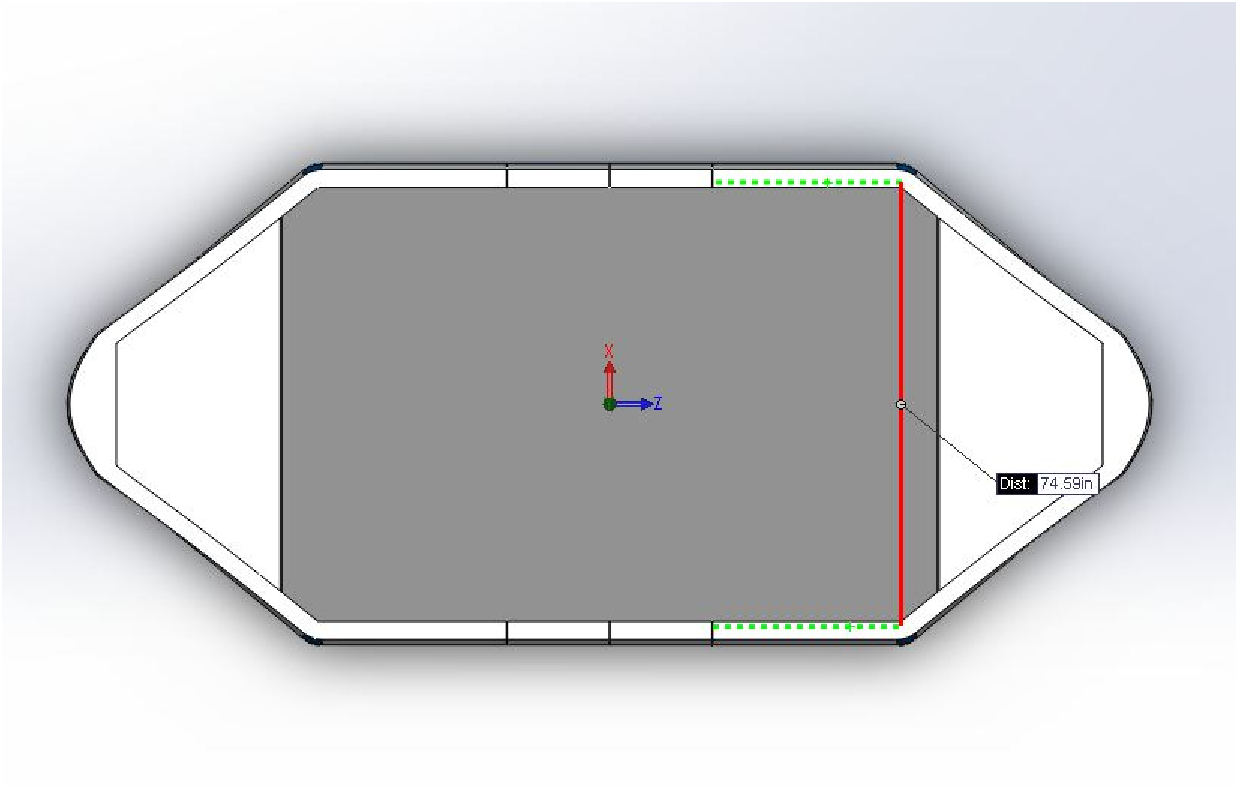



**Figure 26: Floor width is about 75 inches wide**

The seats were sized by measuring seats from automobiles, which were roughly 20 inches in depth by 20 inches wide. If there are three seats on each end of the pod, then the width needed would be 60 inches. However, extra space is needed for passenger comfort. In addition, the cabin tapers as the height increases, so more extra space is needed, which leaves an additional width of 15 inches.

The height of the cabin is about 5 feet tall at 59 inches. This measurement was taken after designing the general shape of the pod. The height is not very reasonable for most people and will be amended in the next design. The next design will require at least 6 feet of height from the floor to the ceiling to accommodate most passengers.

The total weight of the pod is to be set at 5000 pounds. The total weight includes the maximum number of passengers (6 adults), additional cargo or luggage they may be carrying, control systems and electronics, batteries for power storage, the pod unibody, windows, seats, HVAC (Heating Ventilation and Air Conditioning) unit (both interior and exterior) and any additional features including safety equipment (grab bars, floor mats, and fire extinguishers). Eugene Nishinaga, an engineer who previously worked for BART (Bay Area Rapid Transit), stated that assuming 300-500 pounds per passenger is a good estimate. The pod design uses a maximum of 500 pounds per passenger to allow the system to have a factor of safety. At 500 pounds per passenger (3000 pounds total), 2000 pounds is left for the chassis/unibody, interior and exterior trims, windows, seats, HVAC units, batteries, and control systems.

## Interior

The interior of the pod has been designed with capacity and safety in mind. In terms of capacity, six adults can sit comfortably. Initially, it was thought that a four-person configuration would offer the same comforts as a conventional sedan thus making the system more competitive with this current common mode of transportation.  However, the typical car trip transports between 1-2 people and it is reasonable to presume that single party passengers accustomed to public transportation might be willing to travel with another similarly sized party and split a trip. Thus, offering a six-person capacity vehicle offers a lot of versatility while still being able to accommodate a larger party such as a family. Each end of the pod allows for three passengers facing each other. The seats (primarily width) are designed so that even though the seats are next to each other, there is still ample personal space for each passenger. As mentioned above, this is the most common and preferable layout since it allows for free space in the middle for cargo, luggage, etc.

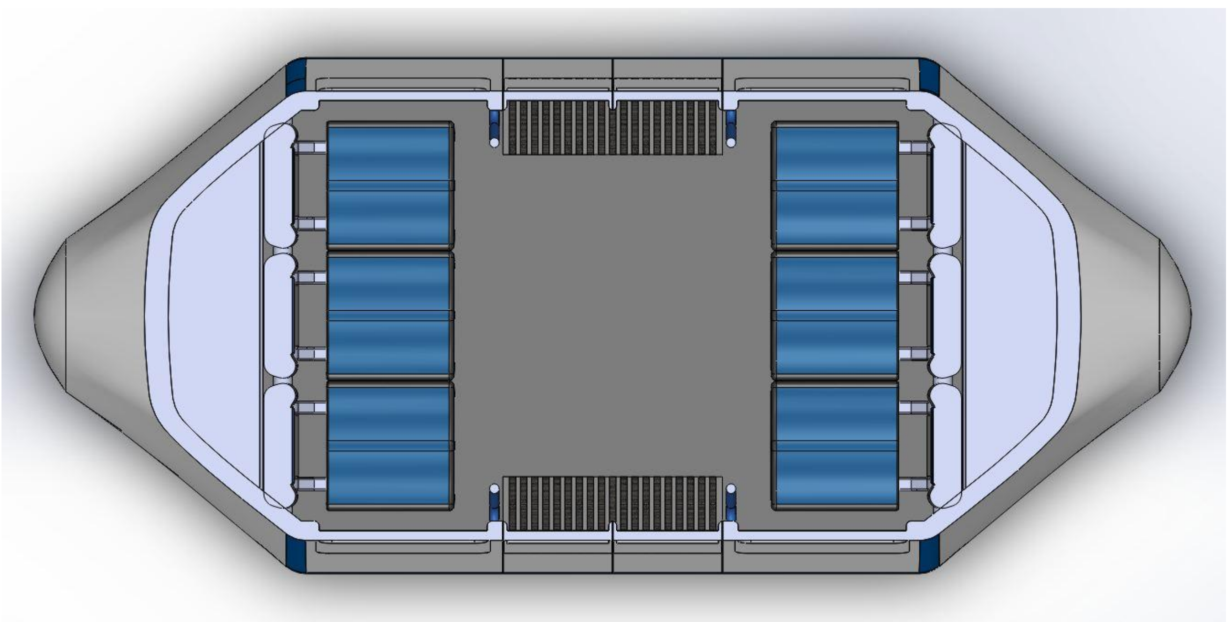


**Figure 27:  Top view (cross section) layout showing the 3x3 seating**

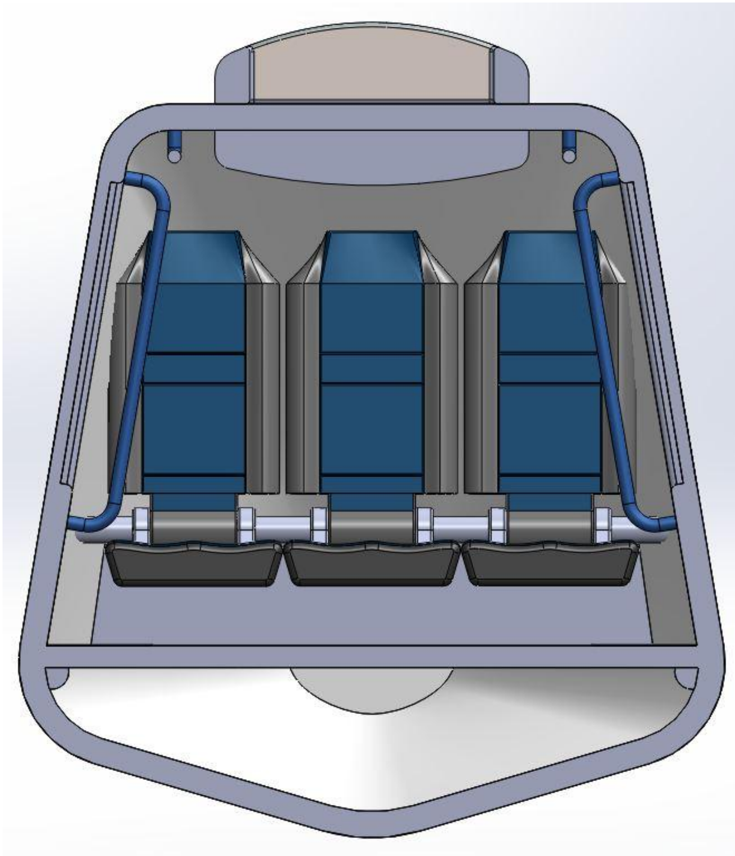


**Figure 28: Front cross-section showing a single row of seats**

Alternatively, three adults can sit on one side while the other row of seats can be folded to accommodate a wheelchair. In fact, if there are two wheelchairs on-board, both rows can be folded. To summarize, three different configurations can be accomplished with this layout.

One feature that was considered extremely important is the ability for the seats to fold. The each row of seats can be folded and unfolded by pressing a button, which actuates the folding action.

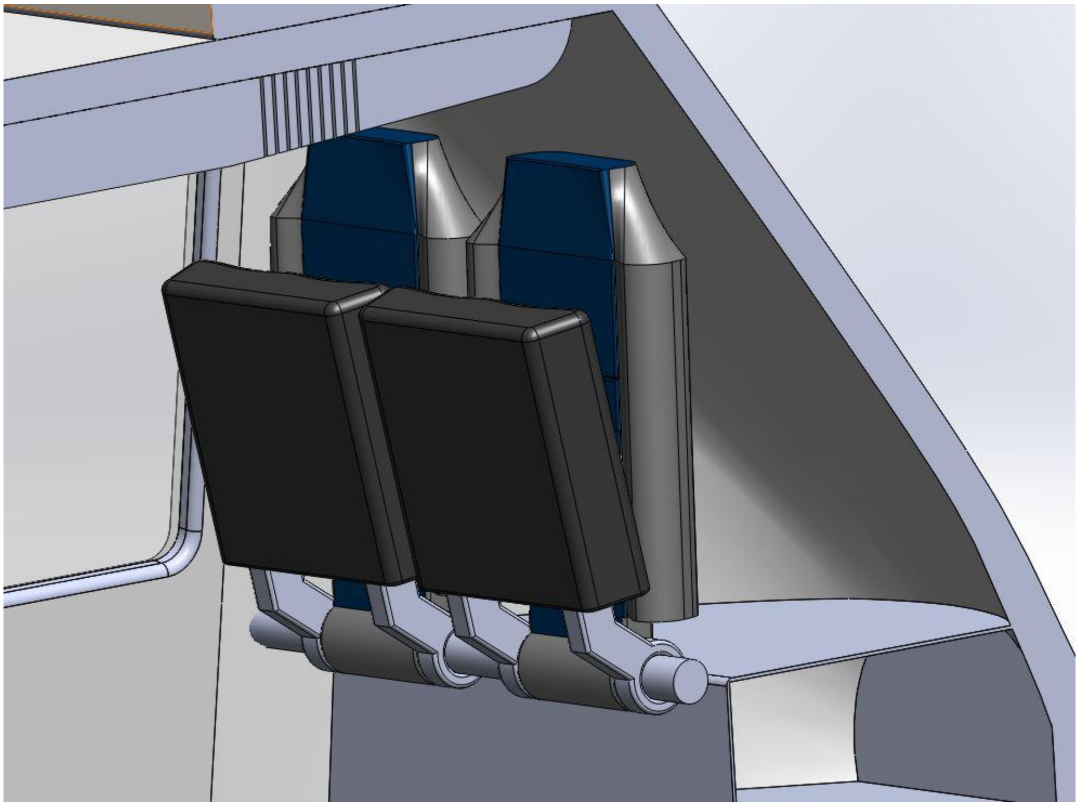


**Figure 29: Cross-section of cabin showing the function of folded seats**

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.

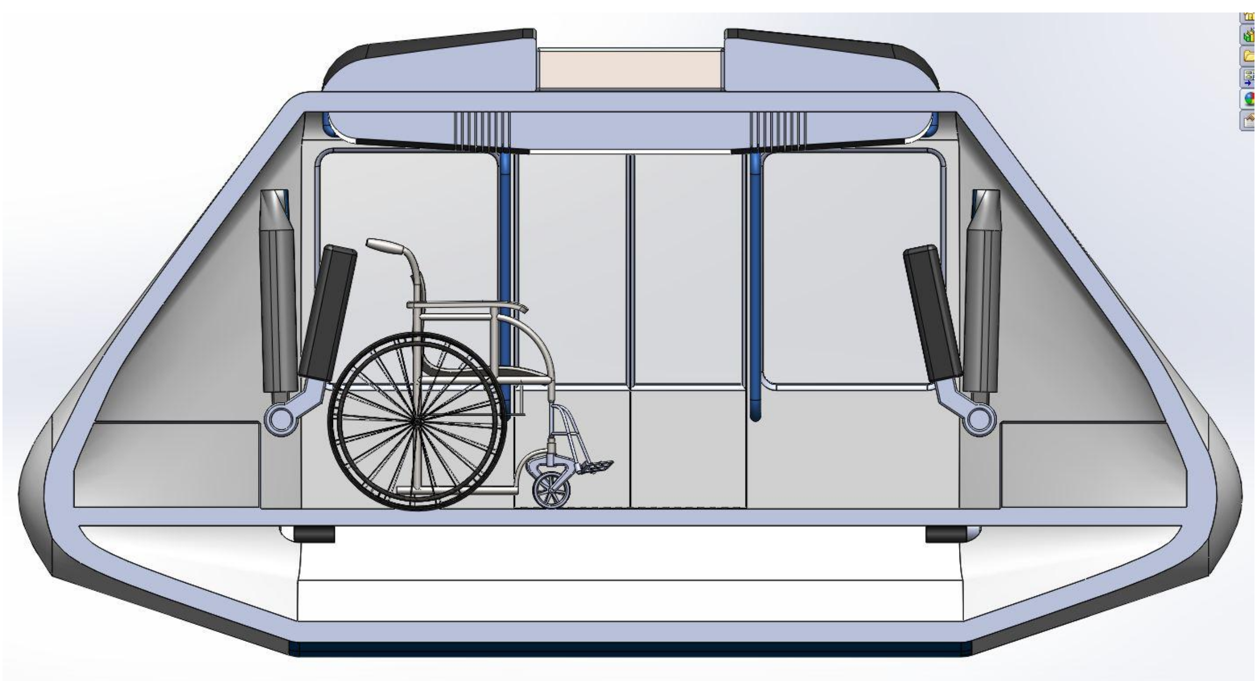


**Figure 30: Side view (cross-section) of both rows of seats folded with wheelchair on one side**

**Figure 31: Angled cross section showing that there is ample room for wheelchair and follows ADA regulations**

If needed, both rows can be folded to fit two wheelchairs (as mentioned above), bicycles, or other various cargo (**Figure 26**).

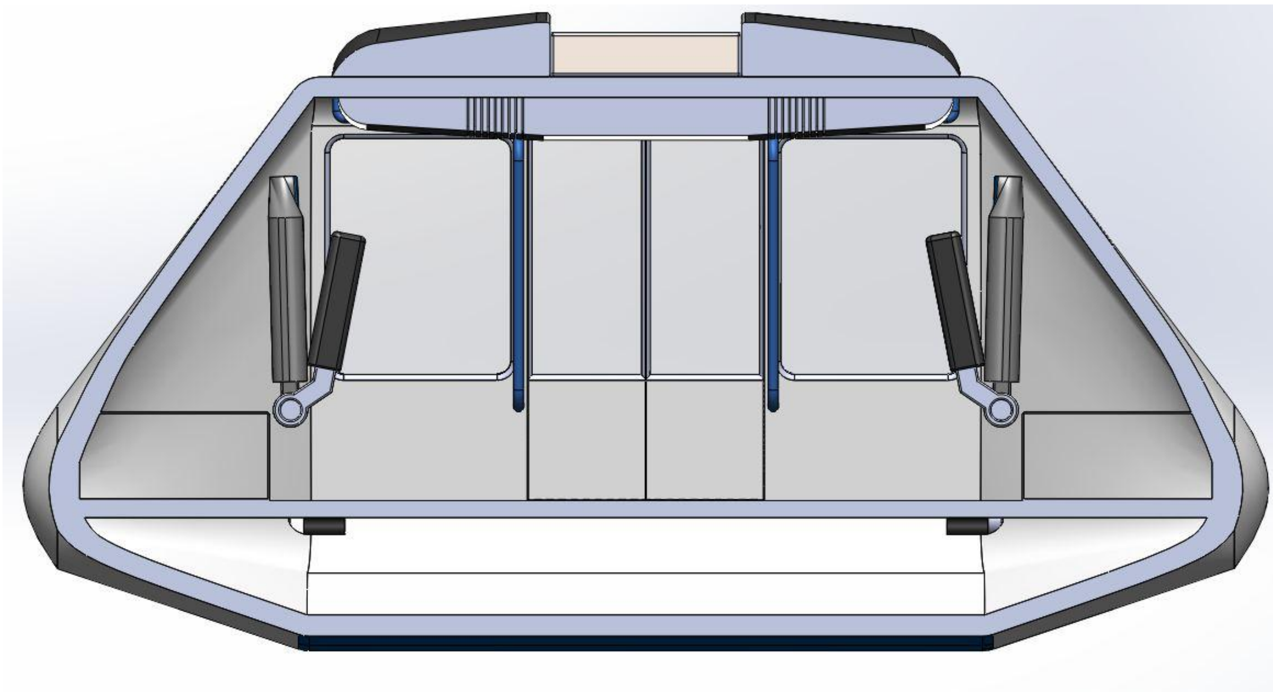


**Figure 32: Side view (cross-section) showing both rows of seats folded**

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)

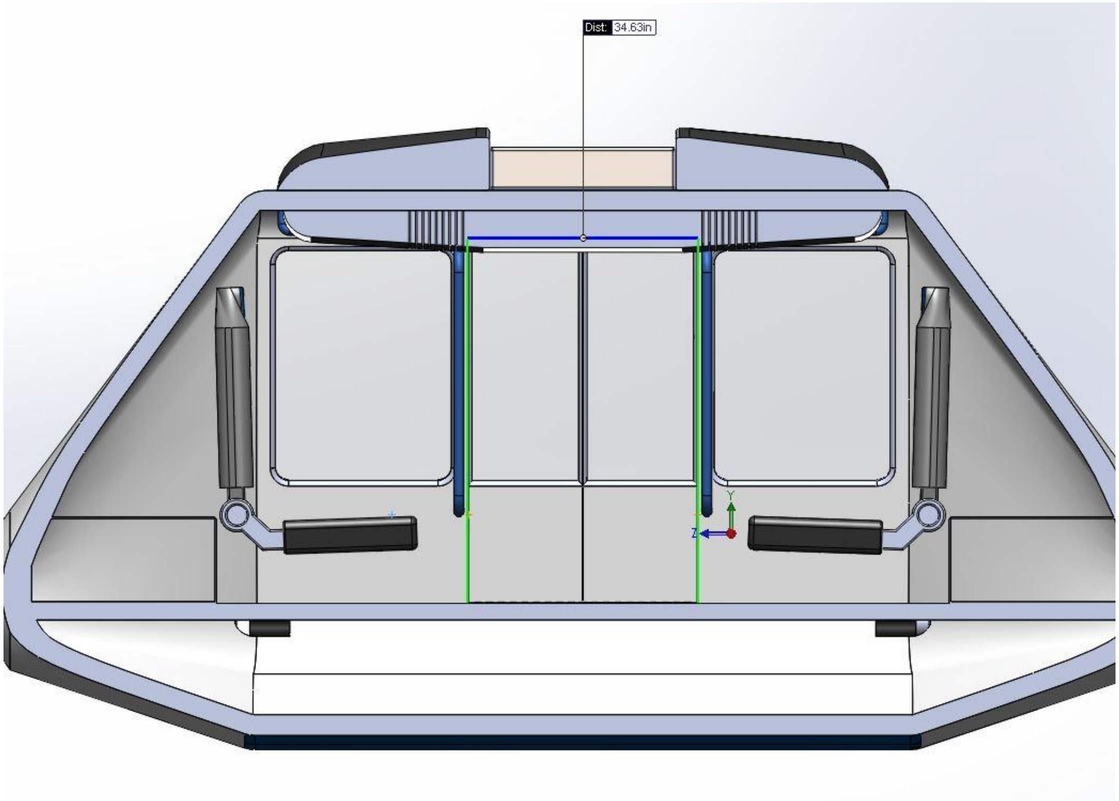



**Figure 33: Door width is measured within the model to be 34.63”**

Each end of the interior of the pod can be used for the storage of control systems or other electrical hardware. Furthermore, there is more space under the main floor of the interior. This space will be used to store batteries and other power related equipment.

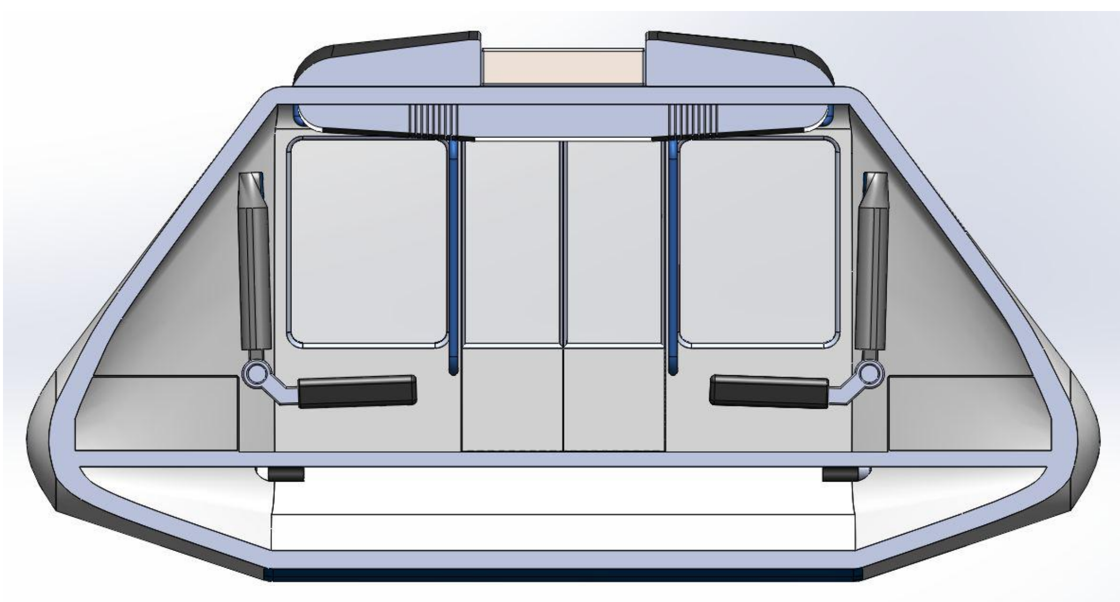


**Figure 34: Storage enclosures at each end of the pod for controls/electronics. Under floor storage for batteries**

In order to deliver comfort into the cabin for the passengers, an HVAC unit must be used. The temperature is constantly monitored and will automatically adjust accordingly. The HVAC unit is integrated with the lighting for a seamless look,as shown in the figure below. Lighting options include the use of LEDs or fluorescent lighting, or even both. For example, fluorescent tubes can be used for the edge lighting, while an array of LEDs can be used for the central lighting.

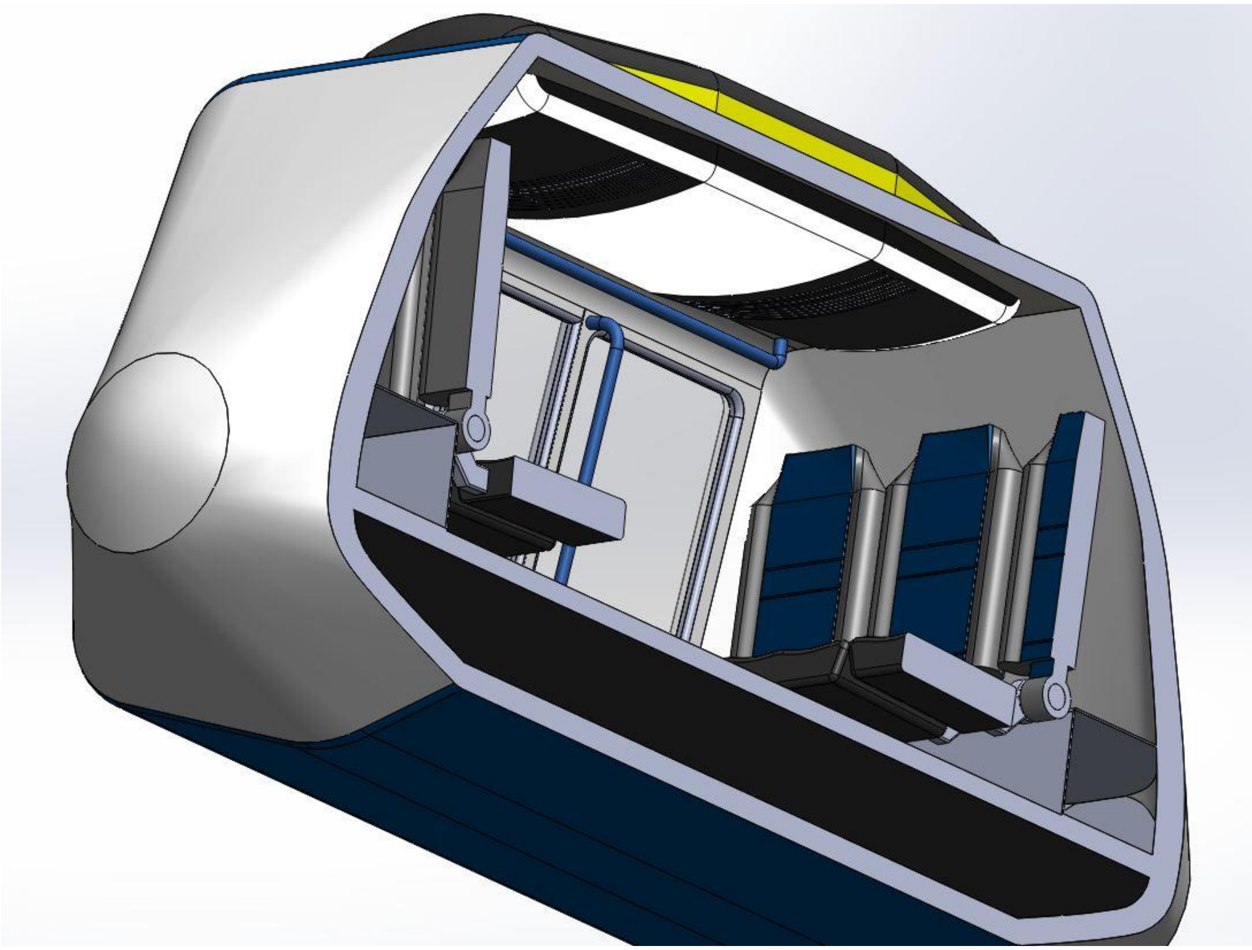


**Figure 35: HVAC and lighting combined**

# Safety

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

The first thing that comes to mind regarding safety is how the structure will hold up if a collision occurs. It is difficult to analyze the crash dynamics of a structure, but it can safely assumed that the noses of the pod will utilize a "crumple zone". Take note that the seats are located forward from the edges of the "main" cabin. This allows the nose to be an effective crumple zone, which essentially absorbs the energy of the collision.

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 pods to prevent any additional damage. During this time, the door may or may not be closed shut; therefore, a manual door release lever is needed. This will be implemented into the design, as well as adding fire extinguishers to each side of the pod 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 pods may or may not experience large forces during acceleration and deceleration.

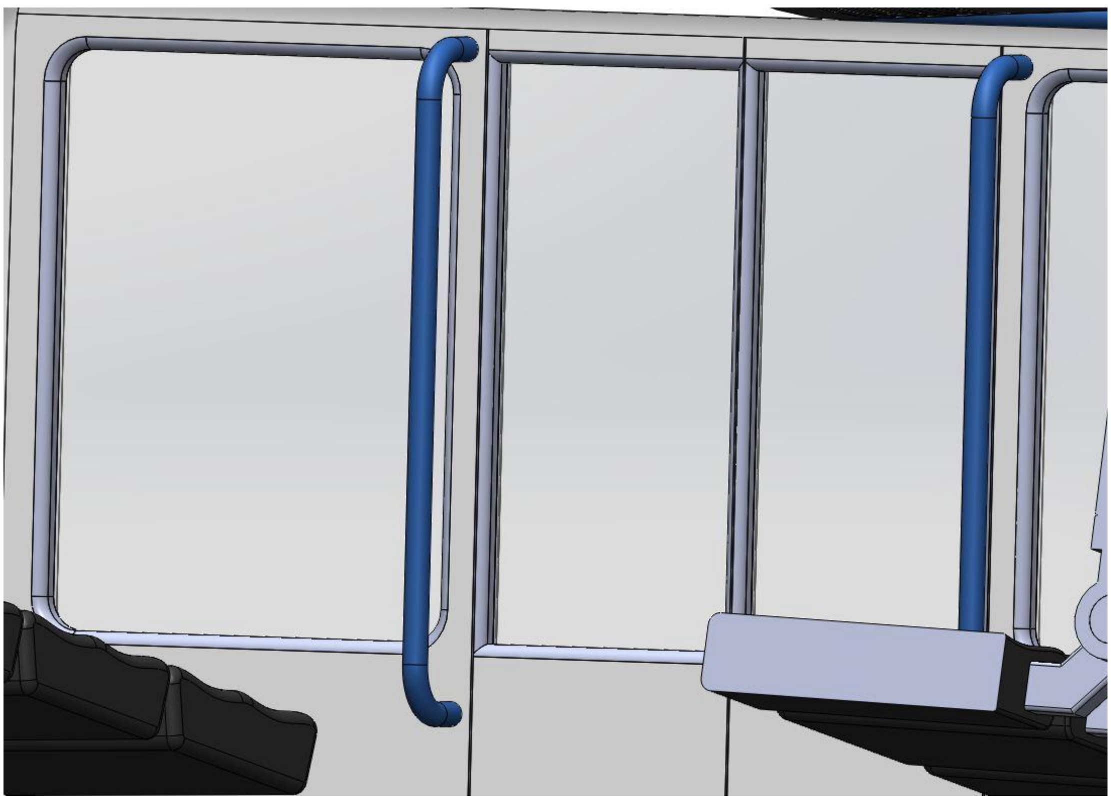


**Figure 36: Grab bars placed on each side of the door**

A vertical grab bar is placed on each side of the door since passengers tend to use them when entering and exiting the pod, which is shown in the above figure. Passengers also use these bars right before the pods reach the station.

Horizontal grab bars are mounted from the ceiling on the right and left side of the pod. 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 the figure 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.

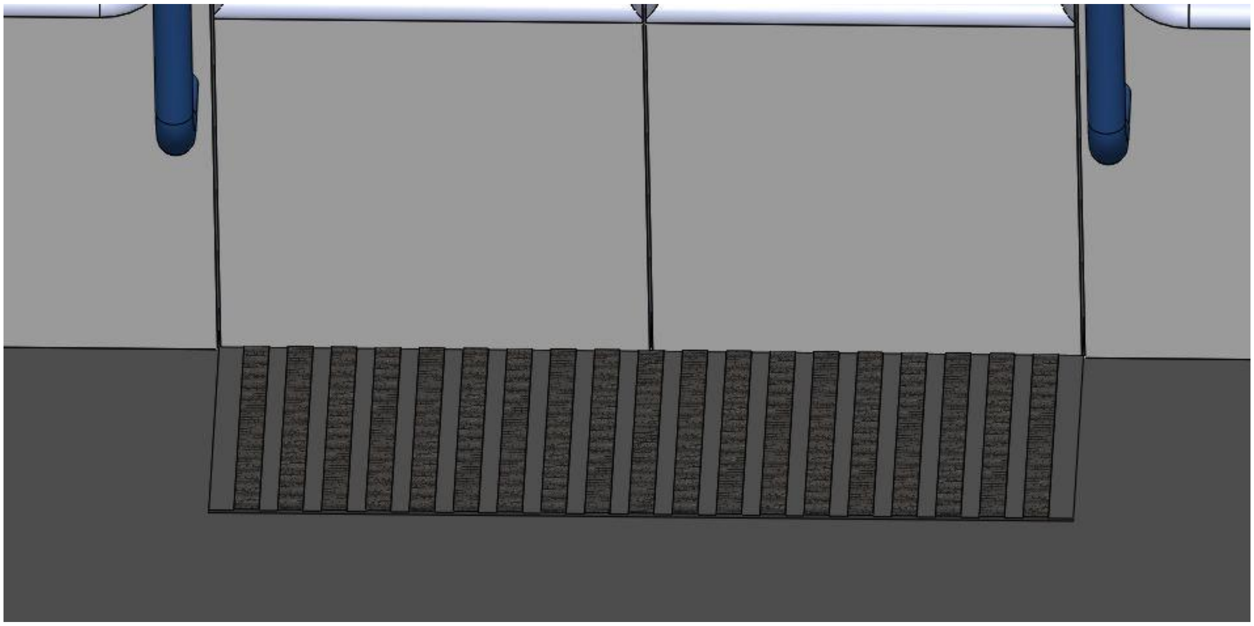


**Figure 37: Rubber mats placed in front of doors to prevent slipping**

One additional and essential safety measure that needs to be added are the use of security cameras. These cameras will be closed-circuit and can capture any incidents that may arise amongst passengers.

# 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 is now tasked with designing a bogie that would incorporate the technology of linear induction motors with the pod car design of the cabin design team. 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.

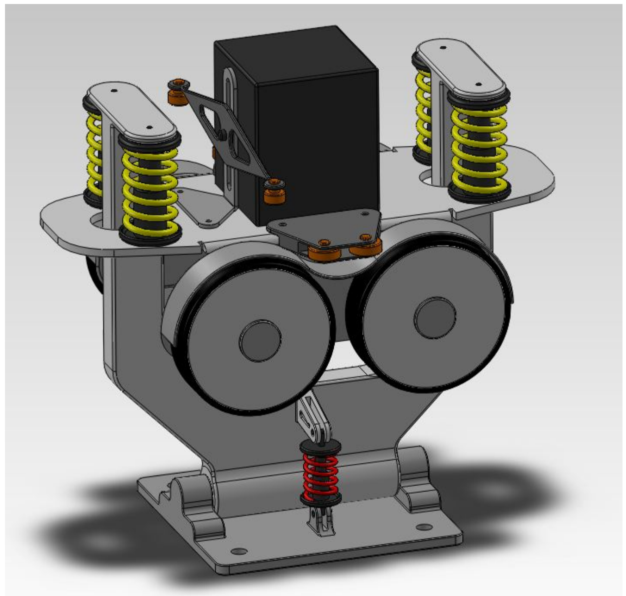


**Figure 38: : General view of the complete bogie design**

## 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 45.5 inches high and is a total of 30 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 which 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 bolts which fasten 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.

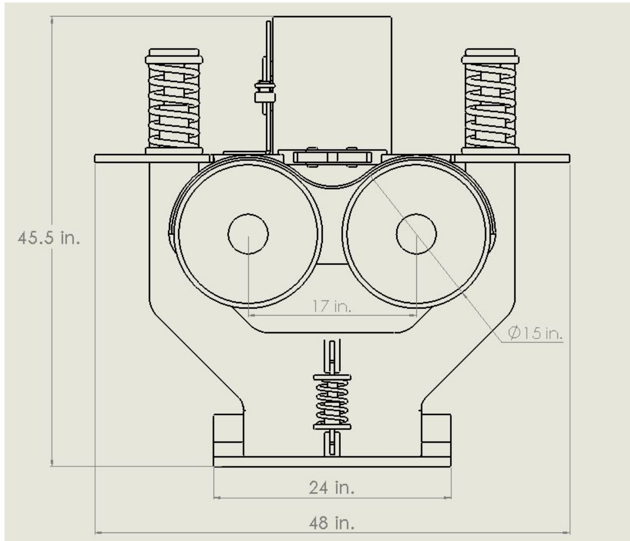



**Figure 39: Side view with dimensions**

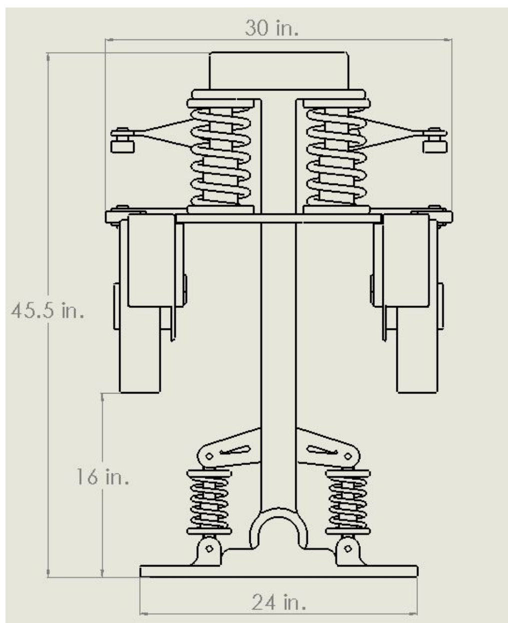



**Figure 40: Front view with dimensions**

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.

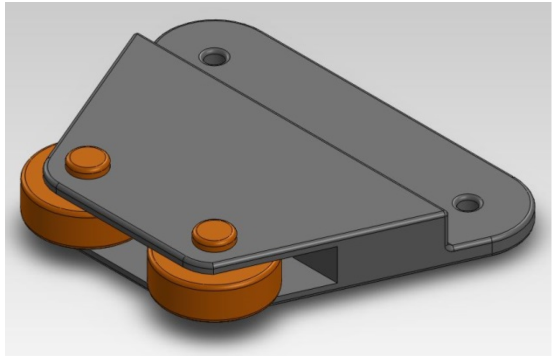


**Figure 41: Bogie guide located on both sides of the chassis**

## 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.

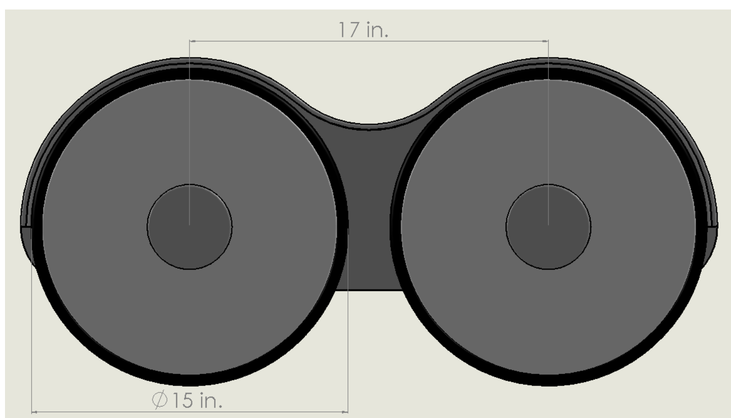



**Figure 42: Wheels and wheel-housing used on the bogie**

The wheels measure 14 inches across and their centers are 17 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 proprietary 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.

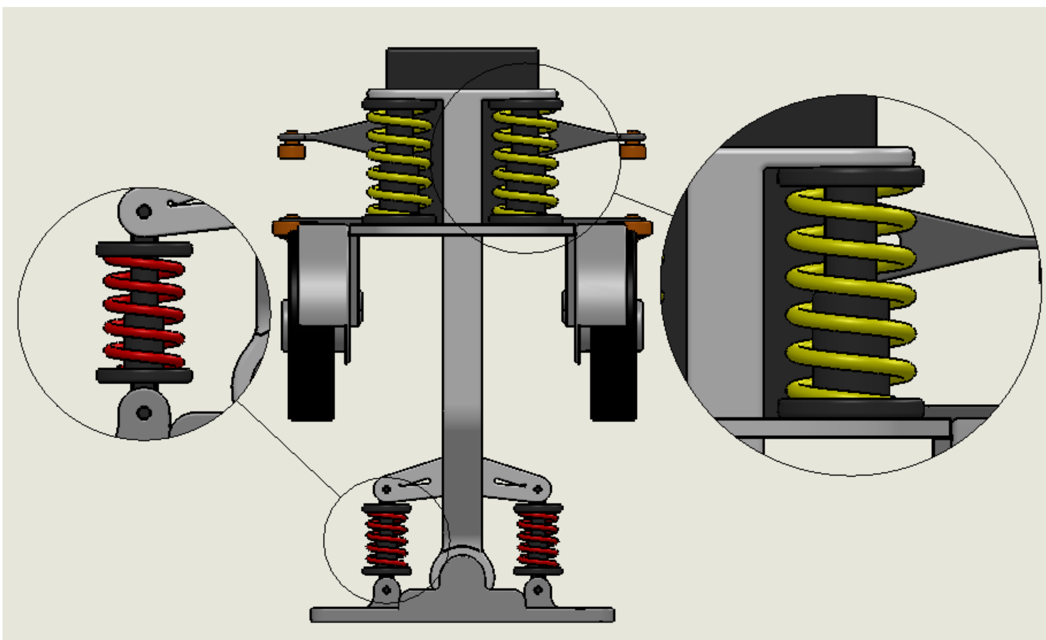


**Figure 43: Detailed view of suspension components & visualization of the bogie's motion**

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 45 mph.

## Switching Mechanism

This bogie's switching mechanism features a vertical displacement component that dictates the path of the bogie during track changing. This switching mechanism's y-component can be manipulated to guide the bogie off the main track for station integration. As depicted in the figures below, the bogie's switching mechanism is offset from the horizontal displacement guides so that contact interference will not occur.

The channels or “grooves” on either side of the guide-way (seen in figure above) are placed just before, during, and after guide-way interchanges. These grooves correspond to a direction the PRT will head once the switching mechanism is connected to it. Locking the wheel in the right groove sends the system to the right and vice versa.

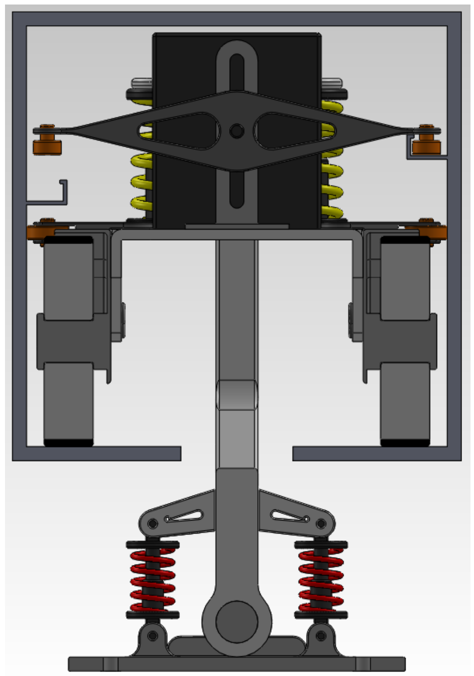


**Figure 44: Cross-section of system showing interface between guide-way and bogie**

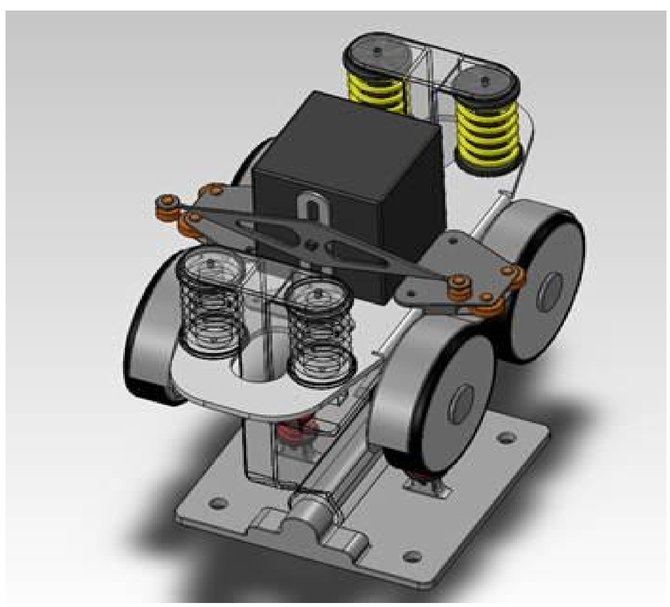


**Figure 45: Top view of switching mechanism on bogie**

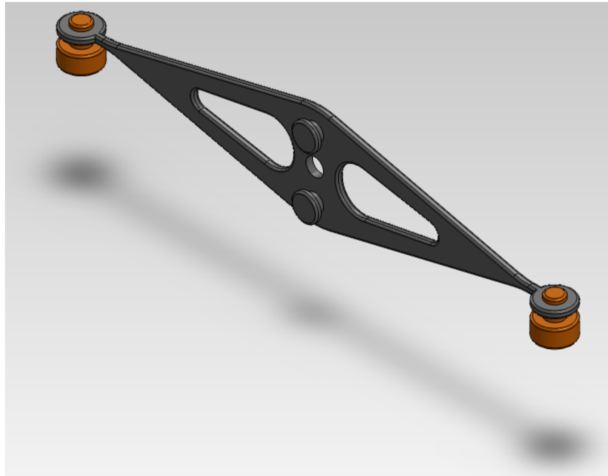


**Figure 46: Switching mechanism's frame**

The switching mechanism is physically made up of a simple frame that is supported by a bracket which will also support a linear actuator to control the motion. At the ends of either side of the frame is a wheel that fights tightly into the guides mentioned above.

# Structure

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. More specific requirements for the structure are presented in Table 3. Those requirements are discussed in more detail in the following section of this report.

**Table 5: Structure Design Specifications**

| Design Aspect | Specification |
|---|---|
| Clearance between grades | 14 ft. |
| Max sagging of guide way | 1 in. |
| Max swaying of guide way | 1 in. |
| Column separation | 40 - 50 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 the below figure, illustration (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 illustration (b). Illustration (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.

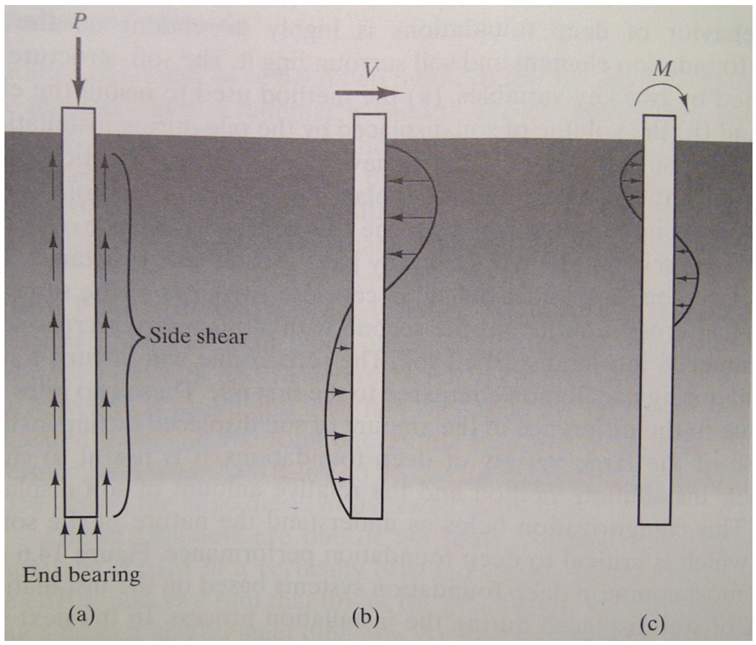



**Figure 47: Transfer of column load to soil in typical deep foundation (Coduto, Yeung, & Kitch, 2011)**

In general, concrete piles are divided into two categories: (a) precast piles and (b) cast-in-situe 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, 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

A preliminary column design is shown in the figure below. This simple concept incorporates 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 terrain.

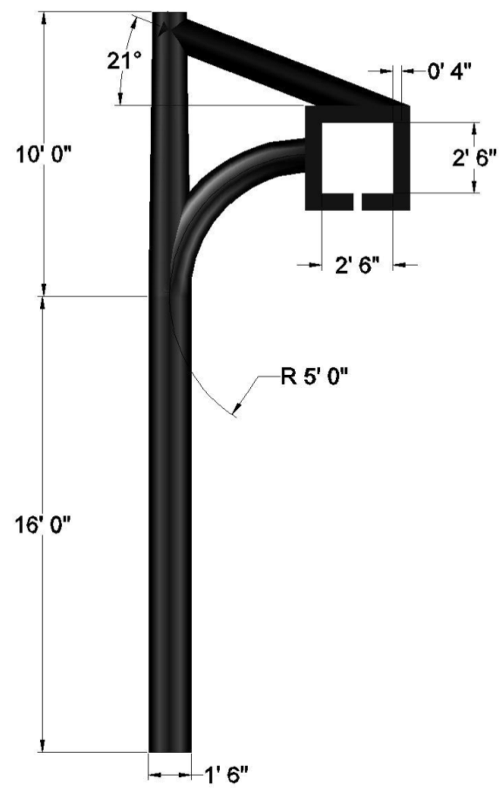



**Figure 48: Column design preliminary concept**

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 the below figure 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.

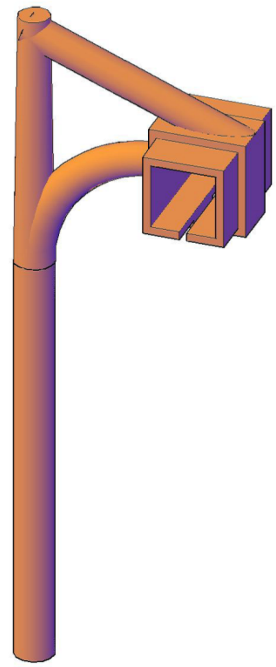


**Figure 49: Isometric view of columns**

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. The following figure 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 only exist at intersections, hence won't be an issue during the straightaway sections in terms of vertical movement. Additional, the guide way will be design 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.

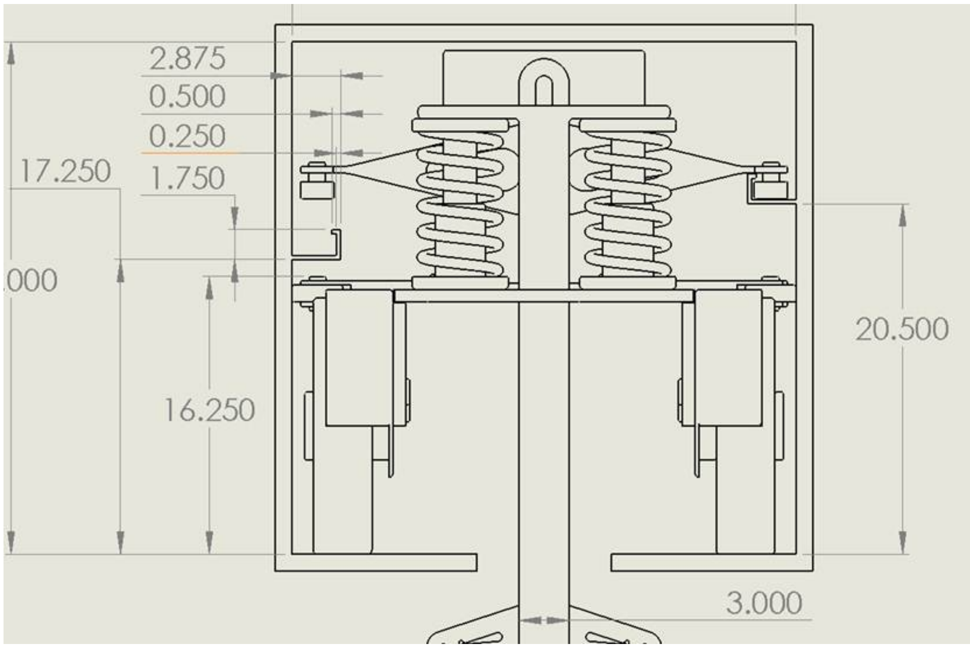



**Figure 50: Guide way design preliminary concept. Switch mechanism is at required height to hook onto right groove, guiding bogie towards the right**

The design team has also considered using a Pratt truss, shown in figure 6, 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.

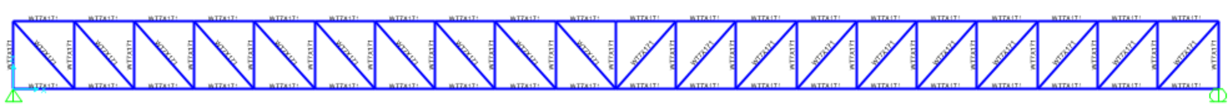


**Figure 51: Pratt truss for guide way**

## Structure's Integration with the Surroundings

The preliminary design of the structure was made so that a friendly integration with the already existing infrastructure is obtained. The following two images depict the structure being incorporated into the city environment. The visual impact created by the structure is minimized by the height of the structure and the slim columns.

**Figure 52: Structure's integration**

**Figure 53: Structure's integration**

# Station

## High Traffic Stations

Linear and angle birth stations are good under certain circumstances, but are not ideal for 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 birth stations were designed to address the solution to the example given above. A pod would pull into a birth 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.

The figure shown 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 births and unload and load. Then instead of backing up, which is done with current angle birth stations, the pod will merge onto a subline 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.

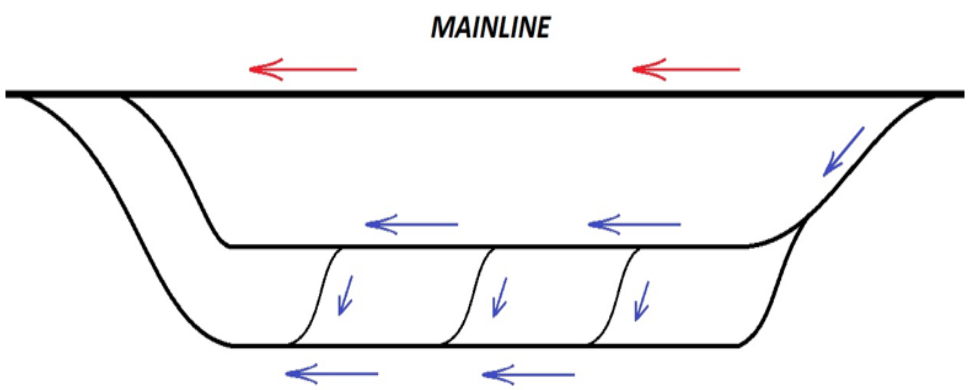



**Figure 54: Configuration for high traffic flow station**

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

## Medium Traffic Stations

Even though the angled birth design is not very practical when dealing with high traffic stations, they are ideal for medium to low traffic stations. PRT systems that are fully operational currently use angle birth stations are Heathrow Airport and Masdar. Heathrow Airport currently runs 21 pods, traveling from Terminal 5 to two different parking structures. The angle birth station design is ideal for this terminal because the system only has three stations, the terminal and two parking structures. The angle birth station presented in the figure 12 would work for this PRT station design. Adding addition angle births is not difficult, which makes this design practical for medium and low traffic stations.

### Station Layout

Shown in the following figure is an angle birth 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 birth.

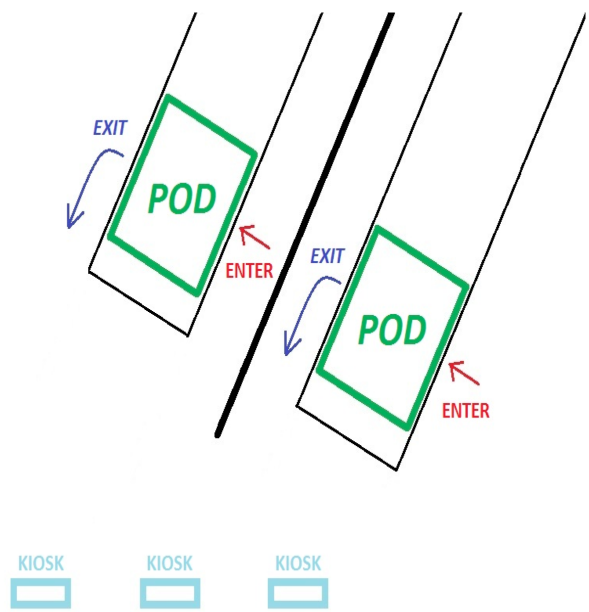



**Figure 55: Layout of angle birth station**

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. These will be taken into consideration next semester, when adequate resources are available.

# Solar

Solar panels can be incorporated into the SuperWay system by placing them on top of the structure. Some of the benefits of having the solar panels on top of the structure include creating minimal visual impact. As shown in the following illustration, 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.

**Figure 56: Solar panels incorporated into the guide way structure**

Having flat solar panels on top of the guide way does have its disadvantages. It will take longer to install and its flexibility of being capable to design along curved guide ways is limited. 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.

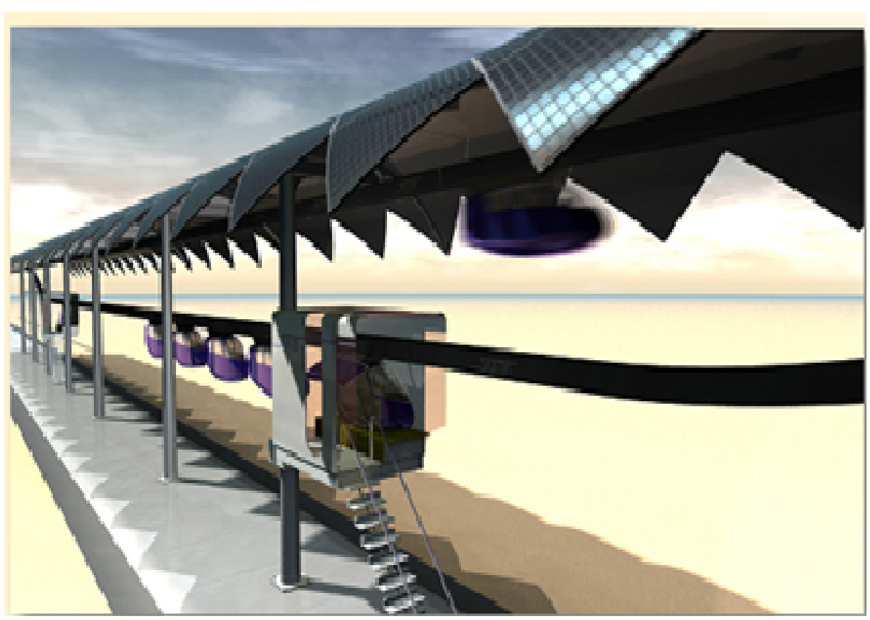


**Figure 57: Curved designed solar panels have the option of being configured different ways to suit both visual appeal and energy production (skytran.com, 2012)**

Given the corridor of San José, CA, the solar team has simulated a solar system that optimizes energy production. System Advisory Model (SAM) is a software program that considers the type of solar panel and inverter, orientation, derate factors, location, and real weather data to predict solar energy production. 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. To properly size the system, adequate derate factors must be assumed (for derate factors used on the simulation see Appendix B). Derate factors to consider are (but not limited to) [5]:

- 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 A.

**Table 3: 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.

**Figure 57: 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. 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) [2]. 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 [2]. 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 [2]. 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 58: 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 59: 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 6: 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<br>If no pod is available at station, route an available pod from a close by station and report wait time<br>1. Receives route request from reservation system.<br>2. Route is scheduled for update to pod<br>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<br>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<br>1. The reservation system subscribes to estimated time metrics<br>2. Metric data will be periodically updated (10 minutes) to the subscribed system |
| 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<br>1. Receives pod check-in information and statistics<br>2. Updates router data |

| Use | Precondition | Source | Action |
|---|---|---|---|
| | | | 3. Checks off pod for check-in until next period<br>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 guide way, collision).<br>1. Alert is sent with level of severity<br>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<br>1. Merge system sends alert message to master controller and waits for acknowledgement<br>2. Master controller acknowledges the alert<br>3. (conditional) If the alert is severe and requires merge intersection changes, the master controller will update the merge intersection settings |
| 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.<br>1. A route request with mid-level priority will be placed for the requested action.<br>2. The route will be scheduled until higher level routes have |

| Use | Precondition | Source | Action |
|---|---|---|---|
| | | | completed.<br>3. The route will be sent to addressed pods |
| Log in | Web application loaded | Admin | Authenticates user to access protected data.<br>1. Users enter username and password<br>2. Administrator is redirected to monitoring screen. |
| Manage Users | Administrator is authenticated Administrator has superuser privileges | Admin | Administrator performs system user management. Admin can add, remove, and modify users through CRUD operation.<br>1. The administrator selects manage users<br>2. Administrator can choose to CRUD users. |
| Monitors traffic | Administrator is authenticated | Admin | Master controller provides a feed of information updated with real-time traffic information redirected from the router.<br>1. Administrator requests real-time feed with web client.<br>2. A frequently updated feed is sent to the administrator to view entire system status.<br>3. Any Emergency alerts and traffic updates are reported to the traffic monitor system will be forwarded to the admin to take corrective action. |

| Use | Precondition | Source | 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.<br>1. Administrator requests immediate routing away from the incident<br>2. (optional) If an accident has occurred that involves injury, severe destruction or system wide failure, contact emergency response (police/ fire)<br>3. Administrator sends update response to send update route |
| 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.<br>1. All received updates are prioritized and executed in order of prioritization.<br>2. Routes are checked against previous request for conflicting instructions.<br>3. The route is sent to the addressed pods |

| Use | Precondition | Source | Action |
|---|---|---|---|
| | | | 4. Addressed pods reply back with acknowledgement<br>5. Update acknowledgement checked<br>6. (conditional) If acknowledgement is not received, go to step 3 up to two times<br>7. (conditional) If send update failed, issue alert. |
| Manage Merge | Master controller need to update intersection settings<br>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.<br>1. The master controller sends the update data to the merge system.<br>2. The merge system will reply with an acknowledgement that the data was successfully updated.<br>3. (conditional) if the data was not updated, it will reply with the error encountered. |

**Master Controller Components**

**Figure 60: 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 users 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 61: 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 62: 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

The 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 63: 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 7: Merge Controller Use Case Scenarios**

| Use | Precondition | Source | Action |
|---|---|---|---|
| Send Alert | Merge system detects a problem | Merge System | The merge system will contact the master controller to report problem |

| Use | Precondition | Source | Action |
|---|---|---|---|
| | while merge is active | | 1. Merge system sends alert message to master controller and waits for acknowledgement<br>2. Master controller acknowledges the alert |
| 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.<br>1. The master controller sends the update data to the merge system.<br>2. The merge system will reply with an acknowledgement that the data was successfully updated.<br>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.<br>1. Merge system sends test command to sensor controllers<br>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.<br>1. Pod controller send pod address information and distance from merge<br>2. (conditional) If the pods distance is closest to intersection, merge system will approve the reservation for the pod and wait for acknowledgement. |

| Use | Precondition | Source | Action |
|---|---|---|---|
| | | | 3. (conditional) If Pod controller does not respond with Acknowledgement, stop incoming pods and send alert to master controller for further instructions |
| 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.<br>1. Sensors send merge system updated data<br>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.<br>1. Master controller requests statistics<br>2. Merge system responds with updated statistics<br>3. (conditional) If merge is not available, issue alert. |

## Merge Controller Components

Figure 64: 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 65: 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 guide way
8. The Autonomous Pod Controller shall check for hardware failure
9. The Autonomous Pod Controller shall check for guide way 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 66: 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 8: 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)<br>An alert is sent to master controller<br>(condition) If critical and immobile, stop and wait<br>(condition) If non-critical and mobile go to nearest station<br>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<br>Pod will "claim reservation" from Merging controller<br>(conditional) If Merging controller sent back reservation offer, pod will proceed to intersection by following reservation point<br>(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 guide way | | 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.<br>The alert is sent to the master controller.<br>The master controller acknowledges |

**Pod Controller Components**

**Figure 67: 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 68: 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 69: 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 70: 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 9: 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<br>Password reset |
| Request Pod at certain time | Logged in | Customer | Request is sent to Master Controller<br>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<br>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. |

**F**

**Figure 71: 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 72: Reservation System Login Sequence**

**Figure 73: Reservation System Pod Request Sequence Diagram**

**Figure 74: 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 10: Conclusion 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 guide way by doing various analyses to test the strength of the exterior and ensure sufficient attachment to the guide way.

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 guide way 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 need 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 will be needed on the center and second supports, and platform bearing as they will be carrying most of the load. FEA is also needed on the bogie guides and switching mechanism.
- 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.
- Size the motor and determine the energy consumption of the propulsion system. This is important to determine the propulsion efficiency which will result in a better estimate of the overall cost. It will also give defined total energy consumption estimates to properly size the solar power system. Sizing the motor will also help size and design the guide way.
- Incorporate the linear induction motor, the bogie and guide way design as a whole.
- Determine and design the means of powering the propulsion system. A power line within the guide way is the current choice of power, but the power electronic specifications (AC vs DC, location of power line) has yet to be determined

# Structure

The next steps in the design of the structures/guide way system include calculating cost, forces, and the overall adequacy of the system. In addition, a meticulous analysis will be conducted to find the period and natural frequency of vibration of the structure to prevent its failure during an earthquake or the loading due to high wind speeds.

# 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. This will require students or experts with architecture or civil engineering 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

Due to the non-existence of 100% solar powered ATN's, research on that topic was limited. Thus a systematic approach was taken to design a solar 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 are to finely define the power distribution and energy storage systems, design the support structure of the solar panels, and integrate them with the guide way, FEA analysis on support structure, and conduct 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 guide way 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 guide way. 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 guide way, 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.

# Chapter 11: References

(2008). *A White Paper on the Status, Opportunities and Challenges in Developing San José's Automated Transit Network (ATN) Project.* San José: San José Department of Transportation.

Alberts, R. E. (1983, May). *Morgantown people mover reliability experience*. Vehicular technology conference.

Anderson, J.Edward. (1988)." What Determines Transit Energy Use? " Journal of Advanced Transportation, Vol. 22, No.2, pp 108-133.

Bae, C.-h. C. (2002). A Successful Transit Oriented Development Experement? *Transportation Quarterly , 56* (3), 9-18.

Baertsch, R. and Swenson, R.B. " Solar-Powered Personal Rapid Transit (PRT): Electric Vehicles without batteries or congestion ", Retrieved October 2, 2010 from: http://www.solarevolution.com/solutions/presentations/ASES_a232_200805.pdf

Bay Area Regional Transportation District. (2006). *Warm Springs Extension Final Environmental Impact Statement.* Oakland: Bay Area Regional Transportation District.

Berger T., Sallez Y., Raileanu S., Tahon C., Trentesaux D., Borangiu T.
Personal Rapid Transit in an open-control framework
(2011) *Computers and Industrial Engineering*, 61 (2) , pp. 300-312.

Booth, C. (2007, November 1). *The rails of morgantown; prt beginnings*. Retrieved from http://www.thedaonline.com/the-rails-of-morgantown-prt-beginnings-1.692751#.UMQGtYNQXKM

Brooks, M. P. (2002). *Planning Theory in Practice* . Chicago: APA Planners Press.

Bureau of Labor Statistics. (2012). *Consumer Price Index, Average Price Data*. Retrieved December 2, 2012, from United States Department of Labor, Bureau of Labor Statistics: http://www.bls.gov/cpi/data.htm

Burger, M. (20, September 2012). *Cabintaxi prt system*. Retrieved from http://faculty.washington.edu/jbs/itrans/cabin.htm

Buys, B. (2005). *Planning in San José: A Community Guide.* San José, CA: City of San José.

California Environmental Resources Evaluation System. (2012). *Appendix G Environmental Checklist Form* . Retrieved from CERES: ceres.ca.gov/ceqa/guidelines/pdf/appendix_g-3.pdf

California Environmental Resources Evaluation System. (2012). *The California Environmental Quality Act.* Sacramento: The State of California.

California Environmental Resources Evaluation System. (2005, May). *The CEQA process Flowchart*. Retrieved from State of California: http://ceres.ca.gov/ceqa/flowchart/

California Public Utilities Commission. (2011). *Rail Safety Reviews*. Retrieved from CPUC Rail Safety: http://www.cpuc.ca.gov/PUC/safety/Rail/Transit/triennialreviews.htm

California Public Utilities Commission. (2012). *Transportation Division*. Retrieved from California Public Utilities Comission: http://www.cpuc.ca.gov/PUC/transportation/

California Transportation Commission. (2011). *About:*. Retrieved from The California Transportation Commission : http://www.catc.ca.gov/

California Transportation Commission. (2012). *Committees*. Retrieved from California Transportation Commission: http://www.catc.ca.gov/committees/index.htm

Carlisle, T. (2010, December 1). *Masdar city clips another $2.5bn from price tag read more.* Retrieved from *http://www.thenational.ae/business/energy/masdar-city-clips-another-2-5bn-from-price-tag*

Carnegie, J., Voorhees, A., & Hoffman, P. (2007). *Viability of Personal Rapid Transit in New Jersey.* Trenton, New Jersey: NJ Transit.

Coduto, D. P., Yeung, M.-c. R., & Kitch, W. A. (2011). *Geotechnical Engineering Principals and Practices.* Upper Saddle River: Pearson .

*Costs summary*. (n.d.). Retrieved from http://www.ultraprt.com/prt/implementation/costs-summary/

Das, B. (2011). *Principles of Foundation Engineering* . Stamford: Cenegage Learning .

DeBolt, D. (2009, September 16). City considers PRT system. *The Voice* .

Desantis, R. (n.d.). Linear induction motor launch system. Retrieved from http://www.personal.psu.edu/rxd5036/blogs/rachele_desantis_e-portfolio/definition%20and%20description.pdf

Ehsani, M. , Gao, Y., Gay, S.E. and Emadi, A. (2010) “Modern Electric, Hybrid Electric, and Fuel Cell Vehicles: Fundamentals, Theory, and Design “, Taylor and Francis Froup.LLC. Ed. 2.

Engel-yan, Joshua, K. C., Saiz, S., & Pressnail, K. (2001). Toward Sustainable Neighbourhoods: The need to Consider Infrastructure Interactions. *Canadian Journal of Civil Engineering , 32*, 45-57.

Federal Highway Administration. (2012). *Highway Statistics Series, Highway Statistics 2010*. Retrieved December 1, 2012, from U.S. Department of Transportation: http://www.fhwa.dot.gov/policyinformation/statistics/2010/index.cfm

Federal Transit Administration. (1998). *Assessment of Transit Supportive Land Use for New Starts Projects.* Washington DC: United States Department of Transportation.

Gastli, A (n.d.) Electromechanical systems and actuators, linear motors. Retrieved from http://emsa.gastli.net/Chapter8/Linear_Motors.pdf

Gibson, T. (2002, March 20). *Still in a class of Its own*. Retrieved from http://www.progressiveengineer.com/PEWebBackissues2002/PEWeb 24 Mar 02-2/PRT.htm

Gordon, D., & Vipond, S. (2005). Gross Density and New Urbanism. *Journal of the American Planning Association , 71* (1), 41-54.

Governer's Office of Planning and Rearch. (2001). *A Citizen's Guide to Planning.* Sacramento: The State of California.

Gow, D. S. (2009). *Vectus news & intel_*. Retrieved from http://faculty.washington.edu/jbs/itrans/suncheon-bay-update-10-2012.pdf

INIST. (2012). *Solar Skyways Challenge 2012-2013.* Santa Cruz, California: The International Institute of Sustainable Transportation.

Irving, J. (1978). Fundamentals of personal rapid transit. Toronto, Canada: D.C. Heath and Company.

James Mokri. (2012, November 12). *Lecture 26 PV Strings and Inverters.* Retrieved from https://sjsu.desire2learn.com/d2l/lp/homepage/home.d2l?ou=126393

Kennedy, C., Miller, E., Shalaby, A., MacLean, H., & Coleman, J. (2005). The Four Pillars of Sustainable Urban Transportation. *Transportation Reviews , 25* (4), 393-414.

Levy, J. (2011). *Contemporary Urban Planning.* San Francisco: Longman Publishing.

Linear motors and its use in transportation (2011). Retrieved from http://mohagami.wordpress.com/2011/08/11/linear-motor-and-its-use-in-transportation-1/

Los Angeles County Metropolitain Transportation Authority. (2005). *Final Environmental Impact Statement/ Environmental Impact Report (FEIS/R).* Los Angeles: LACMTA.

Lu, C., Dawson, G., & Eastham, T. (n.d.). *Dynamic performance of a linear induction motor with slip frequency control*. Available from IEEE. Retrieved from http://ieeexplore.ieee.org/xpl/articleDetails.jsp;jsessionid=0pGhPM2H90s6tJ1SXz727xhhGDjpKSGn4qgpZpNSk0D3TRYR9LR4!382623325?arnumber=332180&contentType=Conference+Publications

Marlaire, R. (2009, October 2). *Nasa partners to revolutionize personal transportation*. Retrieved from http://www.nasa.gov/topics/nasalife/features/unimodal.html

McKenzie, B. S. (2010). *Public Transportation Usage Among U.S. Workers: 2008 and 2009.* U.S. Census Bureau, Economics and Statistics Administration. Washington D.C.: U.S. Department of Commerce.

Minnesota Department of Transporation, (2007). *Chapter 3: General design factors mn/dot bikeway facility design manual*. Retrieved from website: http://www.dot.state.mn.us/bike/pdfs/manual/Chapter3.pdf

Moscovitch, J. L. (2003). Designing Transportation Systems for Active Communities. *ITE Journal* , 34-39.

National Research Council. (1991). *Fires in Mass Transit Vehicles: Guide for the Evaluation of Toxic Hazards.* Washington, DC.

Newman, P., & Kenworthy, J. (2006). Urban Design to Reduce Automobile Dependance. *Opolis*, *2* (1), 35-52.

Paige, T. (2012). *Automated Transit Network Feasibility Evaluation San José Mineta International Airport.* San José.

Pemberton, M. (2012). *Vectus intelligent transport*. Retrieved from http://faculty.washington.edu/jbs/itrans/Vectus-overview-VUK-220612.pdf

*Skyweb express feasibility study*. (2007). Retrieved from http://faculty.washington.edu/jbs/itrans/big/SWEfeasibilitystudy.pdf

Skytran PRT system. http://www.designmagazin.cz/technika/1132-budoucnost-mestske-dopravy-zachrani- skytran.html

Santa Clara Valley Transit Authority. (2012). *Boards and Committees*. Retrieved from VTA: http://www.vta.org/inside/boards/index_standing.html

Schneider, Jerry. (2012, Sept 20). Cabintaxi PRT System. Retrieved 8 Dec 2012 from: http://faculty.washington.edu/jbs/itrans/cabin.htm

Schneider, Jerry. (2010, Nov 23). Cabinlift. Retrieved 8 Dec 2012 from: http://faculty.washington.edu/jbs/itrans/cablift.htm

Siemens AG, Transportation Systems. (2010 Oct 8). SIPEM – Siemens People Mover System (aka H-Bahn 21). Retreived 8 Dec 2012 from: http://faculty.washington.edu/jbs/itrans/sipem.htm

South Coast Air Quality Management District. (2011, March). *FAQ*. Retrieved from Inside AQMD: http://www.aqmd.gov/ceqa/faq.html#What%20is%20CEQA?

Talbert-Barclay, C. (2011). *Curtin's California Land Use and Planning Law.* Point Arena, CA: Solano Press Books.

*The engineering toolbox*. (2011). Retrieved from http://www.engineeringtoolbox.com/rolling-friction-resistance-d_1303.html

The International City/County Management Association. (1988). *The Practice of Local Government Planning.* Washington DC: ICMA.

*Transport.* Retrieved from http://www.masdar.ac.ae/Transport.html

U.S. Census Bureau. (2011). *Commuting in the United States: 2009.* Washington D.C.: U.S. Department of Commerce, Economics and Statistics Administration.

United States Access Board, (n.d.). *Ada accessibility guidelines for transportation vehicles* . Retrieved from website: http://www.access-board.gov/transit/html/vguide.htm

United Stated Department of Transportation. (2012). FTA Safety and Security. Retrieved from Federal Transit Administration: http://transit-safety.fta.dot.gov/United States Census Bureau. (2011). American Fact Finder. Retrieved from US Census Bureau: factfinder2.census.govUnited States Census Bureau. (2011). Center for Economic Studies (CES). Retrieved from US Census Bureau: http://census.gov/cesUnited States Department of Transportation. (2012). Buy America. Retrieved from USDOT Policy Initiatives: http://www.dot.gov/highlights/buyamerica

https://www.altadevices.com/

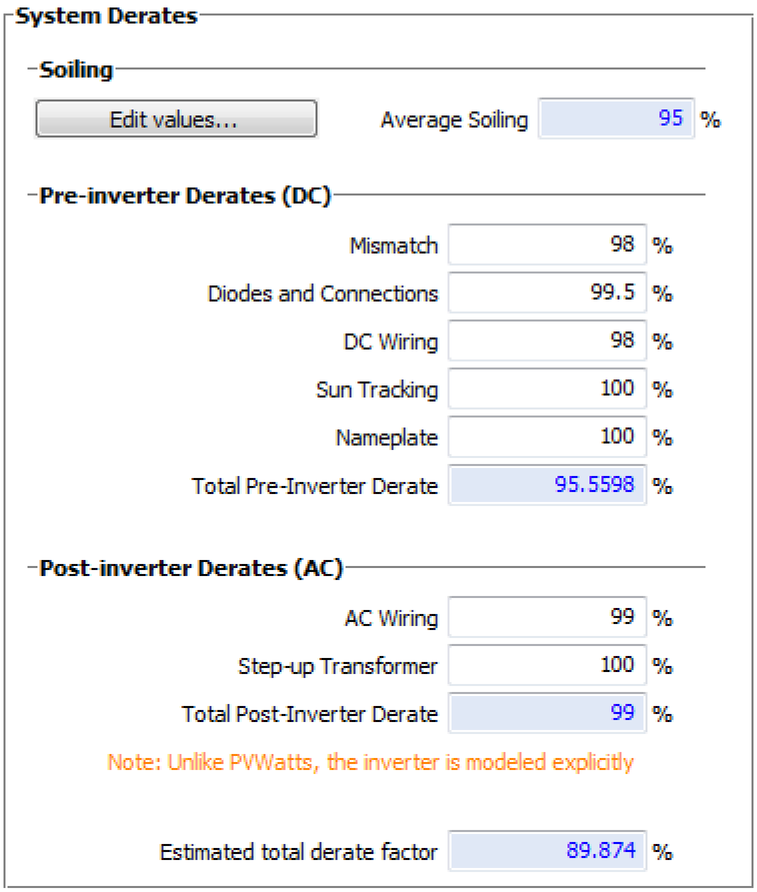
http://solarcar.engin.umich.edu/the-car/

http://www.worldsolarchallenge.org

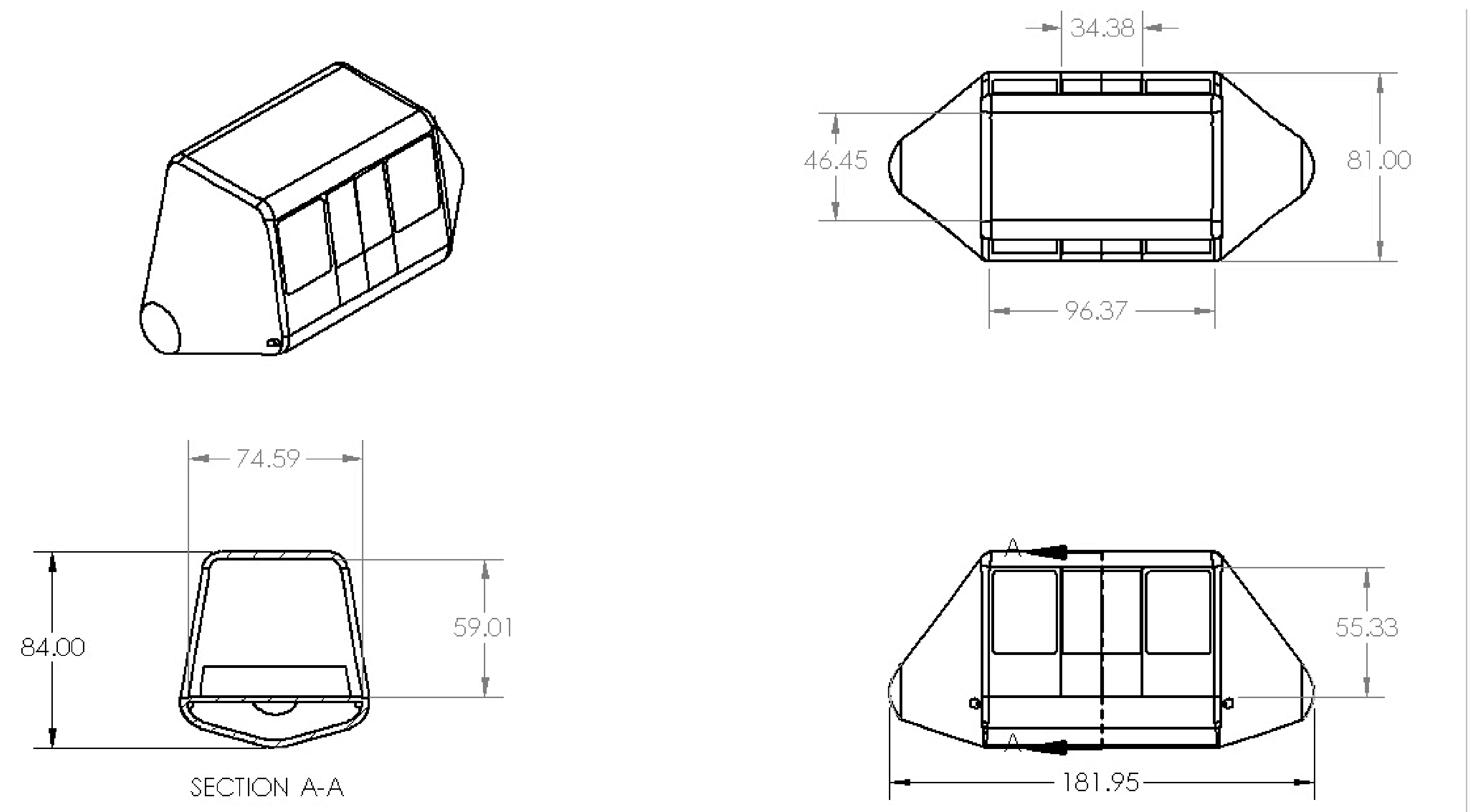
http://americansolarchallenge.org

http://www.santacruzprt.com/

# Appendix A: Derate Factors used in SAM simulation



# Appendix B: CAD Drawings of Cabin




PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

| NEXT ASSY | USED ON |
|---|---|
| APPLICATION | |

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

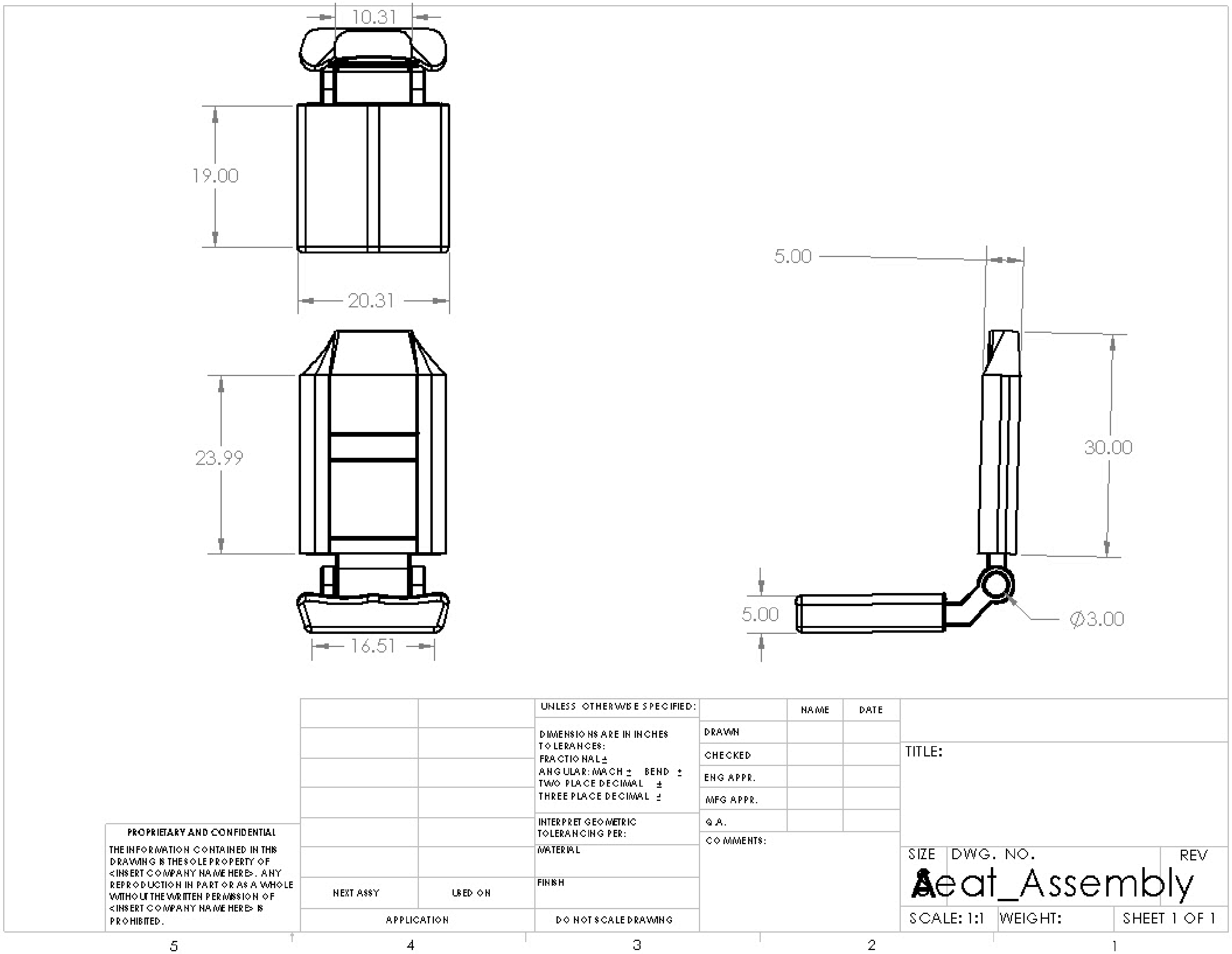
| | NAME | DATE |
|---|---|---|
| DRAWN | | |
| CHECKED | | |
| ENG APPR. | | |
| MFG APPR. | | |
| Q.A. | | |

COMMENTS:

TITLE:

| SIZE | DWG. NO. | REV |
|---|---|---|
| A | Pod_Full | |

SCALE: 1:64 WEIGHT: SHEET 1 OF 1


10.31
19.00
20.31
23.99
16.51
5.00
30.00
5.00
Ø3.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC
TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
SIZE
DWG. NO.
REV
A
Seat_Assembly
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
5
4
3
2
1

# Appendix C: 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 Review |
| 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 |