Mobility in the Floating City:

A Study of Pedestrian Transportation

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ABSTRACT

This Interdisciplinary Qualifying Project worked to study and improve the mobility efficiency of the historic city center of Venice. We evaluated and quantified pedestrian traffic at 10 high volume bridges and 5 boat stops within the highly touristed and popular district of San Marco. A dynamic computer model visualizing pedestrian movement through San Marco was developed in collaboration with the RedFish Group to help understand the resultant effects of urban changes, public works and road closures, and public space management upon pedestrian mobility to ultimately increase mobility efficiency. Traffic through this model was validated by the field counts of pedestrian traffic. Concurrently, we developed a smart-phone navigation application to help both tourists and Venetians navigate the city using the public transit system.

ACKNOWLEDGEMENTS

The team would like to thank the following individuals for their assistance during the course of this project: First of all, we would like to express our gratitude towards our advisors Professor Fabio Carrera and Professor James Cocola for their guidance and input throughout the course of this project. We would also like to thanks Alfonso Morisieri for his valuable recommendations on the smart-phone application, as well as Steve Guerin of the Redfish Group for his invaluable assistance with the pedestrian model.

Without you all, this project certainly would not have made it off the ground or been nearly as successful. The MoVenice team cannot thank you enough for all of your help.

AUTHORSHIP

The members of this team worked to collaborate over the different sections of this report, and every student deserves an equal share of credit as authors. The following describes the sections that each individual student contributed the most towards. Marcus Amilcar contributed the most towards the pedestrian traffic computer model and the corresponding modeling sections of this report. Amy Bourgeois was instrumental in the writing of the Introduction and Executive Summary, and was responsible for the sections pertaining to the pedestrian traffic data collection objective of the project. Savonne Setalsingh researched and wrote the sections on previous studies of boat traffic. Finally, Matthew Tassinari worked to develop the smart-phone application and described its development and functionality in this report.

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EXECUTIVE SUMMARY

Venice's system of islands, canals, and bridges supports two modes of transportation throughout the city center: boat and pedestrian, with automobiles present only at the *Piazzale Roma* entrance to the city. These two modes operate on different planes and are largely independent of one another. Pedestrian traffic, the focus of this project, flows through a dense 160 kilometer network of paved walkways. Efficient flow through this network is challenged by frequent dead ends, narrow walkways, stairs at all bridges. Vendors and public seating along walkways can infringe upon the available travel space. These factors can impede movement and contribute to congestion.

Compounding this congestion within the city, an average of 40,000 commuters and 59,000 tourists enter the city every day, primarily from the *Ponte della Libertá* Bridge connecting Venice to the mainland of Italy. This annual number of tourists has increased from 1.1 million in 1950 to over 16.5 million today, and is projected to continue increasing. Conversely, the Venetian residential population is steadily decreasing from 175,000 in 1950 to 60,000 currently, as many residents relocate to the mainland. One cause sited for this emigration from the city center is the congestion associated with high volumes of tourists.

With the lagoon surrounding the island, there is virtually no room to expand the boundaries of the city. This limiting spatial restriction creates a sustainability challenge which is compounded by the growing number of tourists in Venice. These factors create the need to understand these restrictions and work to improve mobility efficiency within the current infrastructure. This can reduce the strain from all these travelers and ensure the city's ability to support the growing numbers of pedestrians.

Accordingly, the mission of this project was to improve mobility efficiency throughout the historic city center. We worked to accomplish this goal by quantifying pedestrian traffic at critical flow points and incorporating this data into an autonomous agent computer model to visualize mobility throughout the historic center of Venice. In addition, we developed a navigation aid smart-phone application to help facilitate individuals' mobility.

Pedestrian Traffic Studies

To evaluate and quantify pedestrian traffic, this team focused specifically on evaluating different aspects of mobility within the district of San Marco. Focusing on this district allowed us to conduct a thorough study of pedestrian traffic in this area and create a complete visualization of this traffic in the computer model. The population was divided into two distinct groups: tourists and Venetians. Each was matched to their respective likely destinations throughout the day using census data and known locations of various attractors. At 10 high volume bridges, we performed field counts of tourists and Venetians to observe individuals' routes to their destinations. A full day of counts determined five distinct time bracket divisions throughout the day, during each of which data was collected at each bridge to observe hourly changes in traffic. Ridership data available from the public transit system (ACTV) was analyzed to determine passengers' boat usage. To account for mobility impairments, the frequency of different types of mobility impairments was recorded for a full day.

At the 10 high volume bridges for which data was collected, the following traffic levels and proportions of Venetians and tourists were observed:

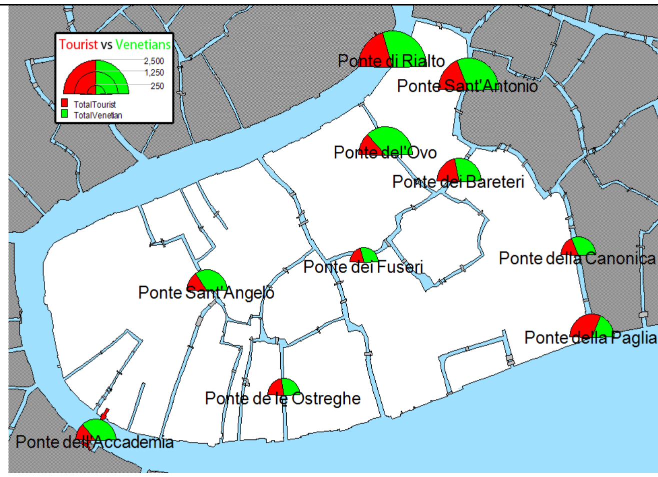

Figure 1 - Map of tourist and Venetian proportions at bridges.

The majority of these bridges in the San Marco district were used primarily by Venetians throughout the day. This data was collected during the month of December, outside major tourist season, and during particularly rainy weather. Higher proportions of tourists can be anticipated during tourist season from April to October.

For the five time brackets throughout the day, the following changes in traffic were observed at the ten high volume bridges and five *vaporetti* stops serving this district:

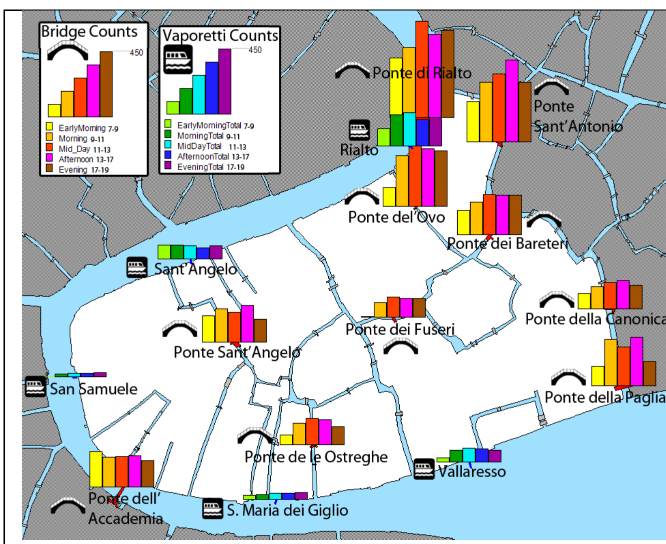

Figure 2- Bridge and *vaporetti* traffic during five time brackets

At the ten high volume bridges and five *vaporetti* stops serving this district, the overall pedestrian flows into, out of, and throughout the district are shown on the following map. High boat and bridge traffic surrounding the Rialto Bridge area indicate movement between the two sides of the Grand Canal. Tourist flow into St. Mark's Square and subsequent dispersion to other areas, such as the district of Castello via Ponte della Paglia or exiting from the Vallaresso *vaporetto* stop, is also indicated.

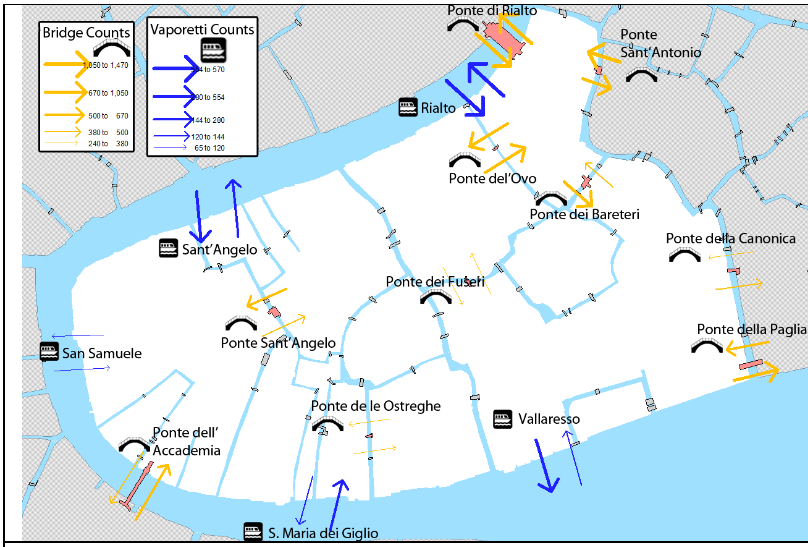

Figure 3 - Directions of bridge and *vaporetti* traffic flow

Future studies can supplement the data collected for the district of San Marco with its 60 other bridges and 5 *traghetti* not studied by this team. Data for other districts can be collected to understand mobility throughout the whole city, specifically studying the large daily influx of day tourists and commuters. Traffic levels at different times of year, such as tourist season, as well as the effects of weather and *acqua alta* should also be studied.

Autonomous Agent Computer Model

To more fully represent types of pedestrians traveling through the city, this team characterized 7 pedestrian types to populate our autonomous agent computer model. Autonomous agent modeling is a sophisticated form of modeling which allows the modeling agents to act independently. For each of the pedestrian agent types, a theoretic "trip" list of possible origins and destinations they would be likely to travel to at times throughout the day was produced and fed to the model, taking into consideration the required travel time and characteristic speeds and styles of movement of each agent. In collaboration with the Redfish Group based in Santa Fe, New Mexico, this team developed the programming logic which would run the model and allow for supplementation with future data.

Since autonomous agents within this type of computer model respond to their environment and choose their most characteristic path options, realistic environments were simulated by adding GIS maps of available pedestrian walkways, common tourist pathways, and census data detailing home and work locations, and known locations of tourist attractions. The concept of the model was to simulate realistic pedestrian movement. A total of over 70,000 agents of our seven different pedestrian types successfully traveled throughout San Marco between 3 or more destinations throughout the day. Route data as collected at bridges and *vaporetti* stops were compared to the operations of this autonomous model. There was a clear distinction between these tourist and Venetian agents simulated in the model, as anticipated, and a correlation with field bridge and *vaporetti* totals.

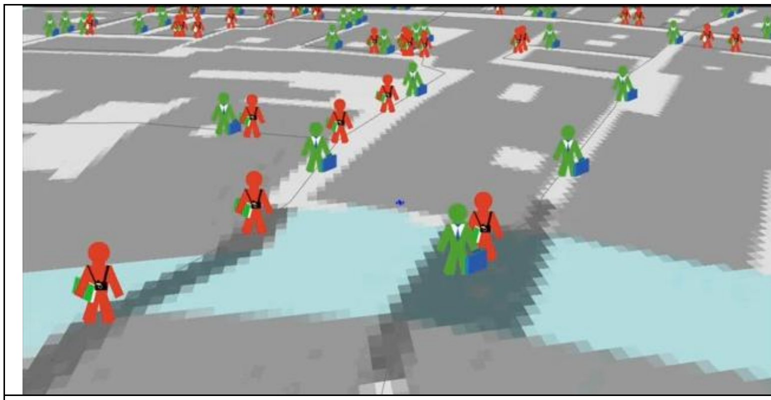

Figure 4 - Screenshot of the autonomous computer model

To increase the scope and usefulness of the computer model, more extensive studies of destinations can be conducted and incorporated into the model to visualize realistic traffic throughout the entire city. Further traffic studies can provide more comparison and validation of the flow simulated by the model. An increased number of more diverse and distinct pedestrian types will create a better representation of mobility in Venice.

Smart-phone Navigation Application

To facilitate individuals' travel and improve mobility efficiency, the team created a smart-phone application. This is a navigation aid tool which provides a number of useful features to help improve individual travel and navigate the city's public transportation system of *vaporetti* more efficiently. A visual mock-up prototype was designed and presented to the Venice Public Transit Authority, the ACTV, for review and consideration for implementation.

Through the use of the smart-phone's GPS capabilities, the user can quickly pinpoint their location on an interactive map of Venice. This map can be overlaid with boat arrival time as well as a trip planner feature that recommends the best route for the user after they have inputted their starting and ending locations. To accommodate users planning trips while on the move, the application provides immediate feedback and a clear display of results. There are also features to view the full boat schedule organized by boat stop or by line. This application's versatility appeals to users both unfamiliar and experienced with the ACTV transit system.

Figure 5 – A display of the application and its features.

To implement the smart-phone application, a programmer and funding to program the application must be identified. Discussion should be continued with the ACTV to ensure their continued interest in and satisfaction with the application.

Conclusions

This smart-phone application will assist individuals traveling through Venice to increase mobility efficiency. The autonomous agent computer model visualizing mobility throughout San Marco provides a tool to study and increase mobility efficiency on the larger, realistic scale. Once supplemented with mobility data for the entire city, a complete visualization will be possible.

1. Introduction

High traffic demands in many major urban cities worldwide contribute to congestion and traffic buildups within infrastructural networks, which result in reduced mobility efficiency. Billions of people traveling every day waste large portions of their travel time in traffic, regardless of their transportation means or travel distance. This wasted time is a direct result of these transportation systems being overwhelmed and rendered inefficient by the inherent congestion and traffic created by such large numbers of individuals using them. For example, in the United States, congestion in urban areas contributes to an annual average of 43 wasted hours per person and $384 per person in wasted fuel.[1] To address these congestion issues, many major urban cities worldwide offer centralized mass public transit systems. These public transportation systems provide inexpensive travelling options to group travelers and reduce such congestion that results from high usage of private transportation and the corresponding traffic density throughout limited infrastructure. These systems can take the form of underground subways, above ground trams, buses, and even boats. In some cases, such as with underground subways, these public transportation systems reduce congestion by operating on a separate plane from other modes of transportation. When systems must operate on the same plane, however, cities can increase their safety and optimize their efficiency with measures such as separated travel lanes for different forms of transportation, rotating traffic lights, and speed limits. Vienna, Austria features designated lanes to safely integrate bike and pedestrian traffic on sidewalks, and a system of rotating traffic lights to integrate private cars, public buses, and public trams in streets. In many cities, pedestrians are also often offered traffic lights to assist them with crossing streets with car traffic since the intersection of these two modes of transportation can be dangerous. In some areas such as Sydney, Australia walkers are controlled by directional pedestrian walking lanes[2] and may be even further divided into slow and fast walking lanes, which has been proposed for the crowded, highly touristed walkways of London, England.[3] By centralizing users into a system of public transportation as well as optimizing all other types of transportation at areas of intersection among transportation modes, cities can increase mobility efficiency and reduce congestion. This can help prevent the amplified congestion caused when construction extends into normal travel routes or accidents occur.

In Venice, Italy, the two possible modes of transportation operate on completely separate planes and do not interact, which provides the city with the potential for highly efficient mobility. Boat transportation throughout the first plane is centralized by the public water-bus transit system, A.C.T.V, which operates boats called *vaporetti* along 20 different waterborne routes around the city center. Since taxis are expensive and private boat use is limited docking space and high maintenance costs, this public transportation is the most heavily used for daily transportation in Venice? However, these *vaporetti* routes run less frequently at night when the demand is lesser, creating planning problems for users unfamiliar with the complicated night schedule. This public transportation system operated solely with boats makes Venice truly unique; even the canals of Amsterdam, the "Venice of the North", offer only tourist boat trips as the most public form of boat transportation.[4] To traverse the city often more quickly than boats, individuals frequently walk. Pedestrian walkways in Venice, called *calle*, which make up the second plane of transportation, range from 1-10 meters in

[1] http://www.fhwa.dot.gov/congestion/factoids.htm
[2] Lopez, Angela. 2006. Assessment of measures to ease pedestrian congestion.
[3] http://www.bbc.co.uk/worldservice/news/2010/12/101202_oxford_st_vid_rbsl.shtml
[4]http://www.canal.nl/en/ and http://www.amsterdam.info/transport/

width and are often winding and lead to dead ends that stop at canals. There are over 450 bridges in the city, each with steps ascending and descending. Varying speeds of travel along these narrow walkways and bridges can contribute to traffic buildup and congestion. Individuals with mobility impairments both have difficulty traveling through this network and can contribute to more congestion. Recently, a number of organizations such as Accessible Venice have been working to facilitate mobility for such individuals by installing ramps, elevator lifts, or tactile paving on select bridges to assist users and raise awareness to create more permanent means of assistance.[5] Beyond the typical traffic and physical constraints of a major city, Venice is subject to an influx of an average of 59,000 tourists per day, but sometimes as many as 150,000[6], in addition to the 62,000 commuters[7] working or studying within the city. Such masses of individuals often entering the city from the same areas contribute to great congestion, leading to mobility inefficiency.

To visualize the flow of traffic throughout the city in its entirety, the most useful tools can be computer models of traffic flow, which simulate peoples' routes and means for traveling throughout specific areas. Some types of modeling can incorporate traffic data collected in the field to more accurately model a location's traffic patterns. These computer models may be used for a number of applications to benefit the city they focus on. For Venice, such a model would assist with as evacuation modeling, gaining a better understanding of the effects of obstructions in pedestrian walkways, and understanding the qualitative effects of urban changes in one area upon traffic in other areas, such as occurs when new boat stops, bridges, shops, or museums are constructed. To help individuals quickly plan efficient routes from location to location, smart-phone and computer applications offer intermodal trip planning services, integrating public transportation as well as walking directions, for a number of cities worldwide. Since Venice's public transit company services over 180 million users per year[8], such an application would be of great use to both increase the transit's convenience and utilization by the user, as well as reduce congestion by centralizing travelers into one system. Venice is currently involved in some trip planning systems for smart-phones.

With its unique geography and infrastructure, Venice is subject to a number of transportation restrictions that substantially affect pedestrians' daily movements. Therefore, in attempts to understand and visualize the unique traffic patterns of Venice and provide valuable tools for benefit the city, previous Venice Project Center mobility teams from Worcester Polytechnic Institute have collected extensive boat traffic data as well as pedestrian traffic data at select bridges throughout Venice[9] and a major square, *Campo San Filippo e Giacomo*[10]. This has contributed to the formation of a computer model of this boat traffic and a model of pedestrian traffic. This pedestrian traffic model features many types of distinct groups of units traveling through a network, in this case walkers. Since the movement of the units throughout the network begins as random and is subsequently limited by constraints placed upon it by the programmer, increasingly realistic and reasonable constraints obtained from a more comprehensive study of Venetian pedestrians' destinations as they travel throughout the city could be obtained and incorporated into the model. This would produce a high level of realism and a highly beneficial model.

[5]Accessible Venice.Venice, 2008.Available from www.comune.venezia.it/flex/cm/pages/ServeBLOB.php/L/EN/IDPagina/23431.
[6]COSES. 2009. Rapporto 141.0 - Turismosostenibile a Venezia.
[7]Pesco, Giuseppe. 2006. Unastimadellapopolazionepresentenel commune di Venezia.
[8]ATCV.The company.Venice, 2009.Available from: http://www.actv.it/en/company/company.
[9]Aloisio, Christopher, Jason Gabriel, Kara Greenfield, and Alexander Kelly. 2009. Venetian mobility on land and sea.
[10]Catanese, Christopher D., DaniceYequay Chou, Bethany J. Lagrant, and Rudy E. Pinkham. 2008. Floating around Venice: Developing mobility management tool.

Building on this previous work, the goal of this project is to improve mobility efficiency in the historic center of Venice by evaluating pedestrian traffic as well as developing tools to facilitate daily travel and visualize movement throughout the city as a whole. The team will work to quantify pedestrian traffic by counting at critical flow points throughout the city, which will be used to influence a computer model of this behavior. In addition to this, the team will help facilitate individuals' daily travel by creating a navigation aid smart-phone application specifically incorporating public transit. With these tools Venice can work to achieve more efficient mobility and better management of the ever-increasing numbers of individuals who travel through this unique city every day.

2. Background

Venice's infrastructure and daily tourist totals make it a unique city to travel through. The city is composed of over 125 separated islands created by over 200 canals, connected by 455 bridges.[11] Venetian mobility is characterized by these three entities: canals, walkways, and bridges. These defining characteristics of the city were developed out of necessity—to transport individuals and goods safely and efficiently throughout the city by adapting to the grassland natural environment.

As a result, travelers must either utilize pedestrian walkways or boats through canals to traverse these islands. Though the historic city of Venice encompasses less than three square miles, traveling quickly, safely, and efficiently can be a challenge due to overcrowding, particularly in areas with tourist attractions, maze-like walkways, and infrequent public water buses late in the day. Traveling from the mainland onto the island of Venice is possible by train, car, or boat; but within the floating city of Venice there remain only two means of transportation: boat or pedestrian.

2.1 ENTERING AND EXITING VENICE

In order to understand mobility within the city of Venice, it is also important to examine how people enter and exit the city since the resident population is often matched or surpassed by the number of tourists entering the city each day.

2.1.1 ENTRANCE POINTS

The northwestern portion of Venice is connected to the mainland of Italy by the *Ponte Della Libertá* (The Freedom Bridge), a 3.85km long span with four automobile lanes and four railroad tracks.[12]This allows access by car, bus, or train. While there are no cars throughout the historical center of the city, there is parking available for cars that cross the bridge adjacent to the *Ponte Della Libertá* in *Tronchetto*.[13]Also in this northwestern area of the city are the *Santa Lucia* train station and the *Piazzale Roma* bus terminal, which are two major methods of arriving in the historical center of Venice by public transportation.[14] Since no individuals can use cars within the city, this public transportation is heavily used.

People may also arrive by air through Venice's international Marco Polo Airport, located 8km north of the city on the Italian mainland, or the Treviso airport.[15] From the airport, people may travel to the city by bus, private water taxis, or Alilaguna water routes.[16]

Cruise ships also contribute to the influx of individuals into Venice. There will be 574 cruise ships calls (dockings) in Venice in 2010, a number expected to increase yearly. These ships are capable of

[11]A Bridge to Venezia.Bridges of Venice. 2009.
[12]Janberg, Nicolas. Structurae: Ponte della. [cited October 8 2010].
[13]City of Venice website: Tourism: How to get to Venice: By car. [cited October 8 2010].
[14]Imboden, Durant and Imboden, Cheryl. Venice for visitors: Arriving in Venice by train. [cited October 8 2010].
[15]Airports guides - Venice marco polo airport (VCE). [cited October 8 2010].
[16]Trip advisor - Venice: Transport and cost to airport. [cited October 8 2010].

discharging up to 13,000 people in a single day[17]. These travelers are discharged at the docks located in the southwestern area of the city.

Beginning operations in April of 2010, the new shuttle train called the People Mover has the capacity to transport 200 people per carriage and 3,000 people per hour from *Tronchetto* island to *Piazzale Roma*,[18] where they can easily switch to other modes of transportation to take them deeper into the city.[19] This People Mover is part of an overall effort to facilitate entrance into the city. It will allow individuals to park at *Tronchetto*, then take this People Mover to *Piazzale Roma* and enter the city proper.[20] Previously, access between *Tronchetto* and *Piazzale Roma* was limited to one bus, one *vaporetti* line, or walking.[21]

2.1.2 DAILY TOURIST AND COMMUTER TOTALS

While pedestrian traffic is not hindered by the clutter of any motor vehicles along the streets, the large daily influx of tourists and commuters greatly hinder pedestrian mobility.[22] Since housing and the costs of living are higher in Venice than on the mainland, large numbers of individuals live in Mestre, often called the "dormitory of Venice" or other areas on the mainland and commute daily into the city.[23] Commuters entering the city to work and study number as much as 62,000.[24] These commuters primarily use public transportation to enter the city from the *Ponte della Libertá* and then disperse from *Piazzale Roma* or *Ferrovia* to their work or school locations within the city. Conversely, 18,000 Venetians leave the city every day to work or study in other areas. The net influx of commuters is therefore 44,000 per day.

During the warmer months when tourism in Venice is at its highest, typically stretching from March to November,[25] as many as 150,000 tourists can be present in the city every day.[26] While a portion of these tourists have arrived on a previous day and originate from hotels in the morning, the majority of these tourists are day tourists who enter the city in the morning, primarily from the *Ponte della Libertá*.[27] 34,000 day tourists enter the city on an average day. Combined with the 25,300 overnight tourists already present, this average daily total of 59,300 nearly matches the 60,000 resident populations.[28] Further combined with the net number of commuters entering the city, an estimate of between 89,000 to 100,000 individuals enter the city every day. The total numbers of these individuals entering the city at various locations are shown in Figure 8.

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[17]Venice termanalpassaggeri - ship schedule. [cited October 8 2010]. Available from
[18] People mover moves out (sort of). 2010
[19]Ibid.
[20] Palazzo, Francesco. People mover is working. 2010
[21] People mover moves out (sort of). 2010
[22] Howard, Deborah, and Quill, S. 2002. The architectural history of Venice. Singapore: B.T. Batsford, Ltd.
[23] Pesco, Giuseppe. 2006. Una stima della popolazione presente nel commune di Venezia.
[24] Ibid.
[25]Ibid.
[26]Natanson, Phoebe. 2009. Death in Venice: Venetians to stage their own funeral. ABC News/Travel, 9/29, 2009. www.abcnews.go.com/Travel/venice-residents-plan-funeral-city/story?id=8946058.
[27] The Venice Report: Demography, tourism, financing and change of use of buildings. 2009. Cambridge University Press
[28] Ibid.

2.1.3 INCREASING TOURISM

As a major tourist destination, Venice has experienced steadily increasing numbers of tourists that are projected to continue increasing. The following graph shows the growth of overnight tourists in Venice, or the number of tourists spending one or more nights in a hotel or other overnight accommodation.

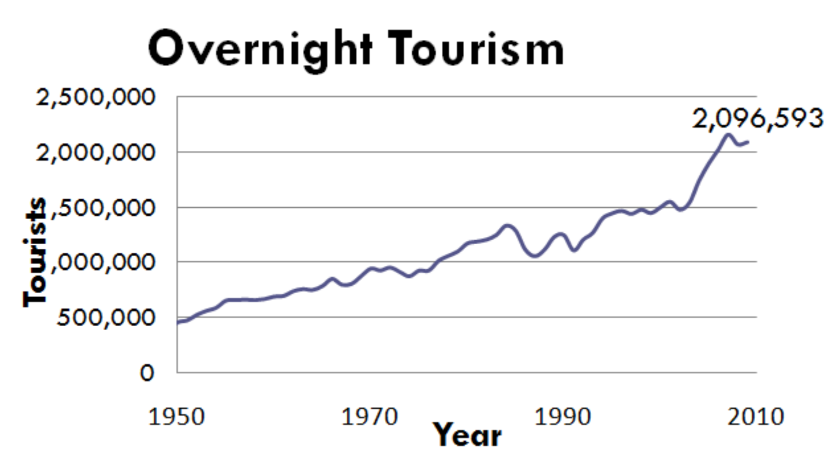

Figure 6 - Increases in Overnight Tourism

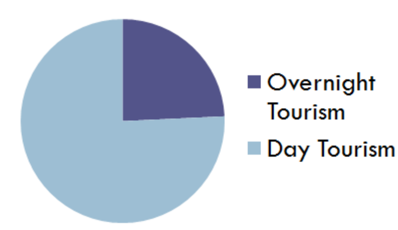

Figure 7 - Overnight and Day Tourism Proportions

Overnight tourism represents only a portion of total tourism in Venice. Of the 16.5 million tourists that visited Venice in 2007, 12.5 were day tourists entering the city in the morning and leaving by the end of the day.[29] Only 4 million stayed overnight in Venice, This total number of tourists has increased from 1.1 million in 1951 to 16.5 million in 2007.

[29] The Venice Report: Demography, tourism, financing and change of use of buildings. 2009. Cambridge University Press

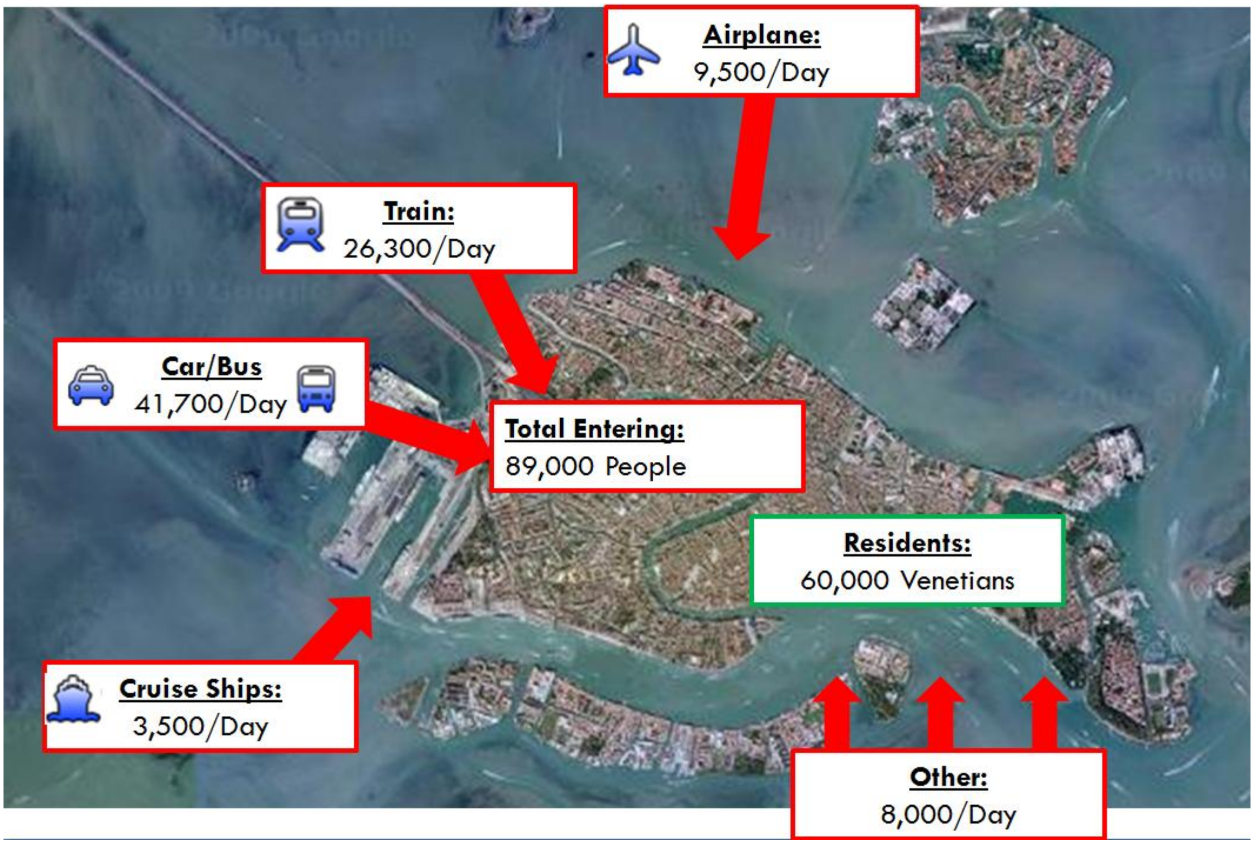

Figure 8 - Total individuals entering the city daily

These commuter and tourist entrances create enormous congestion and traffic jams, particularly in streets connecting the three major tourist attractions referred to as the Tourist Triangle (*San Marco, Ponte Rialto,* and *Galleria dell'Accademia*), [30]forcing residents to rely on back routes and less crowded *calle* to travel quickly, despite sometimes increasing the distance they must walk to reach their destination.[31]

[30] Davis, Robert C., Marvin, Garry R. 2004. Venice: The Tourist Maze. Los Angeles: University of California Press.
[31] Davis, Robert C., Marvin, Garry R. 2004. Venice: The Tourist Maze. Los Angeles: University of California Press.

2.1.4 DECREASING RESIDENTIAL POPULATION

The current population of Venice is 60,000. This number has been decreasing since 1951, when it was at its peak of 175,000. [32]

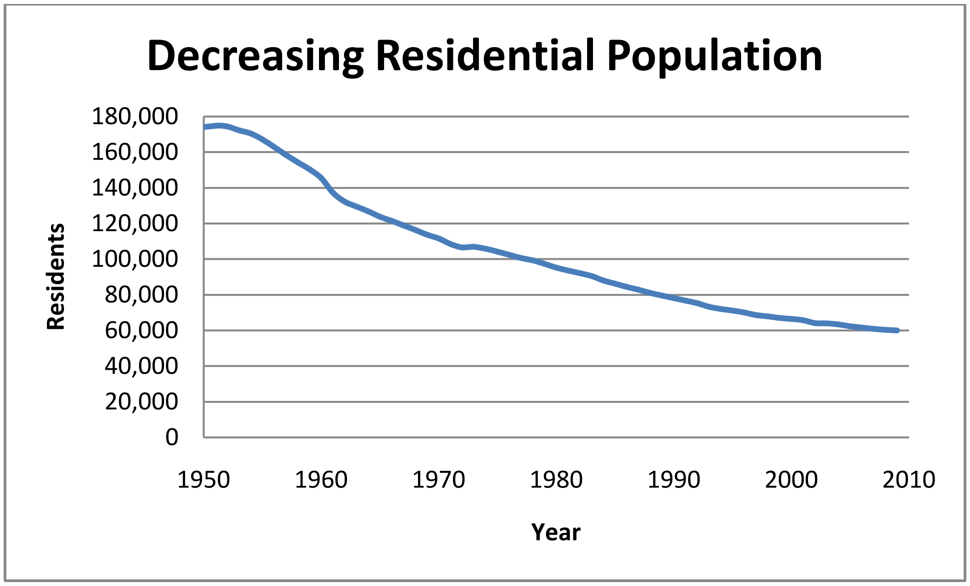

Figure 9 - Residential Population of Venice over Time

Many of these residents relocate to the mainland of Venice. Some causes leading to this emigration of residents are the rising property costs, low availability of housing, rising cost of living[33], limited job variety, and increasing tourism. This increasing tourism corresponds to increased congestion and mobility difficulty—cited as an aspect of Venetian life that former residents dislike.[34] The following two bar graphs represent the important of various factors about Venetian life that Venetians, shown in the first graph, and Venetians who moved to Mestre, dislike. Both groups cite mobility as one factor they dislike.

[32] Cittá di Venezia: Statistiche-Popolazione
[33] The Venice Report: Demography, tourism, financing and change of use of buildings. 2009. Cambridge University Press
[34] Lund, Jenny, Joshua Luther, Tobin McGee, and Stephanie Miskell. 2008. Life in the "City ofWwater". p. 48

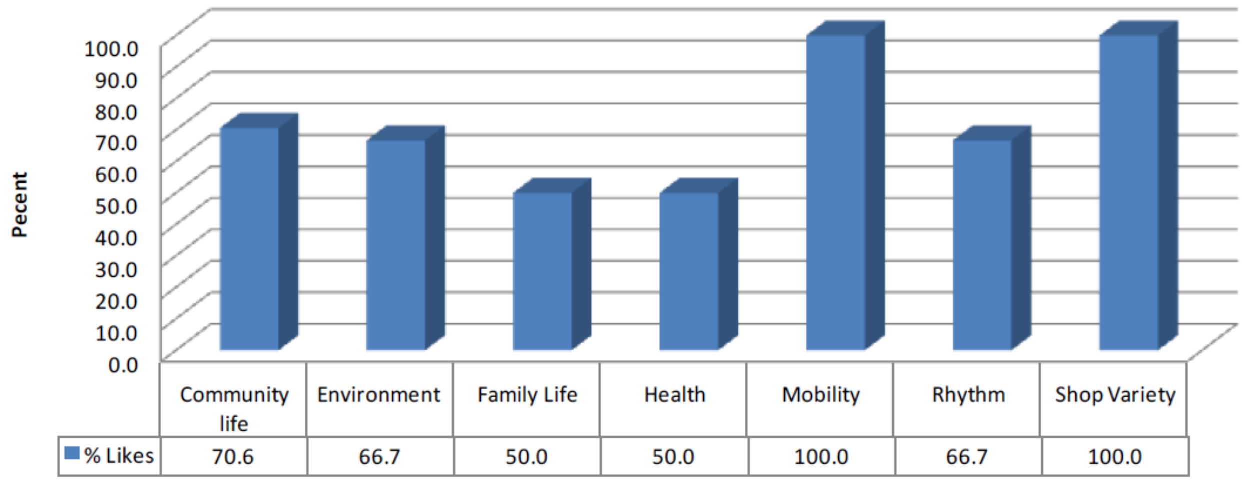

Figure 10 - Factors about Venetian life that current residents dislike

Figure 11 - Factors about Venetian life that former residents who moved to Mestre dislike

2.2 BOAT TRAFFIC IN VENICE

One of the two major modes of transportation throughout the city is boat transportation. These boats can travel through the Grand Canal, the lagoon, or the hundreds of canals.

2.2.1 HISTORY OF VENETIAN CANALS

The city of Venice is traditionally believed to have been founded in the year 421 A.D. by local fishermen and inhabitants of the Italian mainland seeking refuge from invading barbarians.[35] The ancient Venetians began to shape the character of the city by modifying the archipelago of grassy tidal islands that originally existed by draining and dredging in order to provide more land for construction as the city expanded. This draining and dredging of the grasslands formed the first canals to allow transportation between islands.[36] Despite the manmade changes, the original geography of the area dictated how the majority of the city would be laid out. For example, the Grand Canal's nearly two and a half mile backward "S" path follows the course of an ancient river.[37] The canal network enabled goods to be moved throughout the city with relative ease. Today, are more than 200 canals that are linked through the city, forming a dense urban network unlike any other in the world. [38]

2.2.1.1 BOATS AND MOBILITY

Canals themselves would not aid mobility without watercrafts to populate them. As it has been all throughout Venetian history, any heavy transport within the city is done by boat. The iconic Venetian boat is the *gondola.*[39] These unique keel-less boats were used primarily by the wealthy and paying visitors in the city's early years but are used almost exclusively for tourism these days.[40] There are also several *traghetto* ("ferry" in Italian) crossings across the Grand Canal.[41] The *traghetti* are standard gondolas stripped of their luxurious fittings and operated at separate points along the Grand Canal in between the bridges. For the cost of just 50 cents travelers are offered safe passage over the canal. The *traghetti* offer an excellent glimpse into how the city moved historically, yet they are still a practical modern function.[42]

Figure 12 – a Venetian *Traghetto*, or "ferry."

[35] Howard, Deborah, and Quill, S. 2002. The architectural history of Venice. Singapore: B.T. Batsford, Ltd.
[36]Ibid.
[37] A view on cities - Venice: Grand canal.
[38]Cessi, Roberto and Foot, John.Encyclopaediabritannica online.
[39]Cessi, Roberto and Foot, John.Encyclopaediabritannica online. "Venice". [cited October 9 2010].
[40] Davis, Robert C., Marvin, Garry R. 2004. Venice - the tourist maze. Los Angeles: University of California Press.
[41]Drake, Cathryn. 2008. Venice crossings: Wall Street Journal2008, sec World News.
[42]Ibid.

In 1881, a mechanically powered water-bus public transit system was introduced to the city of Venice.[43] This new transportation solution was viewed upon with disdain by the *gondola* rowers, but eventually the obvious benefit of this ease of travel with the new system won over to population.[44] These steam powered ships were called *vaporetti* beginning in 1926 derived from the French term *bateu a vapeur,* "Steam Boat;" v*aporetti* is the name still used today.[45] The *vaporetti* are now the dominant form of boat transportation used by commuters and travelers today.[46]

Boats contribute immensely to the economic success of Venice and can connect all major points in the lagoon.[47] Before the introduction of motorized boats in the late 19th century, row boats were used for the transportation of people and goods. There were an estimated 10-12000 *gondole* and a similar figure of smaller row boats that navigated the canals from the 15th to the early 19th century. After WWII, motorboats gained popularity in Venice, modernizing boat transportation and as a result affecting boat traffic on the canals.

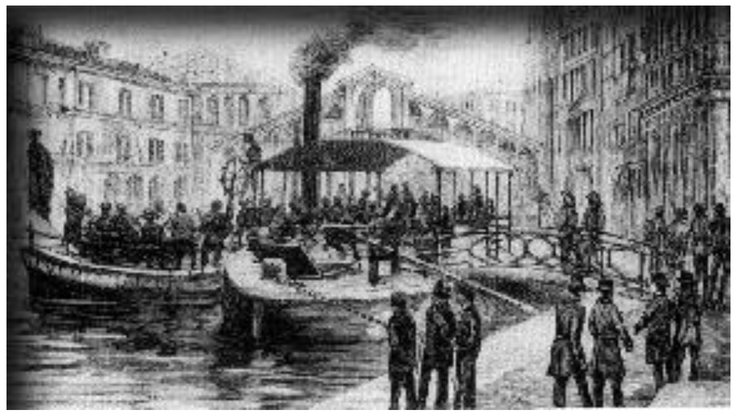

Figure 12- The first Venetian water-bus or *vaporetto*. A revolutionary step in the city's mobility.

Boat traffic in Venice is composed primarily of boats used for the transportation of people and cargo. The means of boat transportation available in Venice to people can be broken down into public and private transportation. Public transportation can be further subdivided into three types of boats: taxis, gondolas, and *vaporetti* (waterbuses). Taxi boats in Venice serve two functions; they operate in a manner similar to taxi cabs in the US, carrying passengers to their desired destination by the most direct route, but also can function as livery boats such as

Figure 13 - Boat Traffic on the Grand Canal.

[43] ACTV: The history. 2009 [cited October 9 2010].
[44]Ibid.
[45] Merriam-Webster: "vaporetti". [cited October 9 2010].
[46]ACTV: The history. 2009 [cited October 9 2010]. Available from http://www.actv.it/en/company/thehistory.
[47]Winkler, Bernhard. 1995. Project for mobility in the Venice municipality. In Cities on water and transport., eds. RinioBruttomesso, Marta Moretti, 108-109. Venice: International Centre Cities on Water.

live limos when not performing taxi duties. *Gondole* were once the main form of boat transportation, but are currently used exclusively by tourists for sightseeing.[48]Lastly, *vaporetti* are public motorboats that transport passengers to specific locations, following the routes operated by the *Azienda del Consorzio Trasporti Veneziano* (ACTV). Motorized boats are also used by for other services in Venice such as the postal service, emergency services, and garbage collectors. Private boats are the personal boats used for recreation by Venetians. Previous WPI Interdisciplinary Qualifying Project teams and other organizations have studied the movement of these different boat types along the canals and at various major and intermediate canal intersections throughout the city.

2.2.2 TRANSPORTATION OF PEOPLE

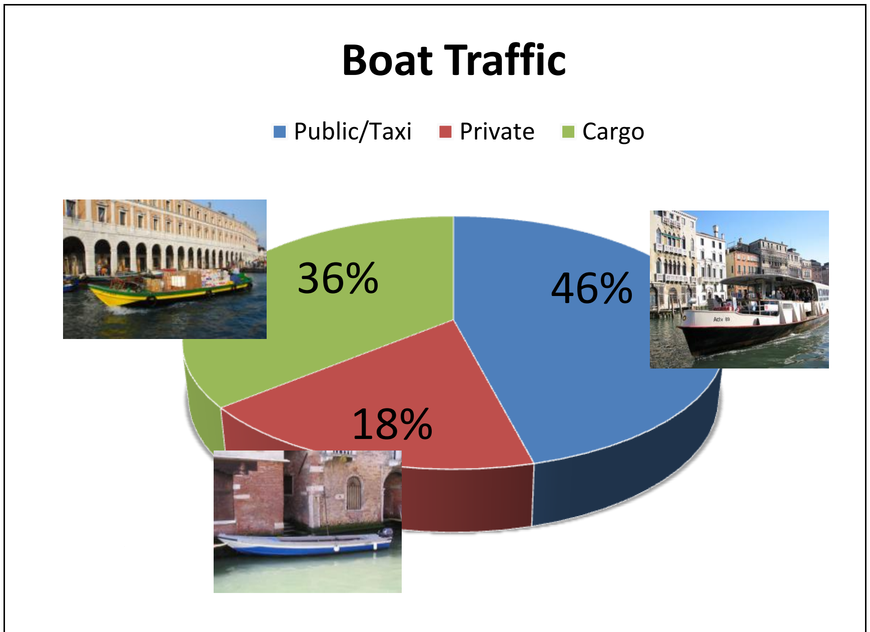

Figure 14 - Break down of boat traffic in Venice

Boat traffic in Venice is primarily caused by three main types of boats: public transportation boats, private transportation boats, and cargo boats. Public transportation comprises the largest portion of Venetian boat traffic at 46 percent. Private transportation constitutes the smallest, at 18 percent, and cargo transportation is responsible for 36 percent of Venetian boat traffic.[49]These three types of boats have different behaviors and their own unique schedules of operation, which are outlined below.

2.2.2.1 PUBLIC TRANSPORTATION

Taxi boats usually operate from early morning to late evening, and wait for clients to request a ride to their destination. The taxi boat will take their customers to their destination following the best route possible (shortest and least trafficked), and return to its stating location after each trip they make.

[48]Chiu, David, AnandJagannath, and Emily Nodine. 2002. The Moto Ondoso Index: Assessing the Effects of Boat Traffic in the Canals of Venice. Pg. 22.
[49]Catanese, Christopher D., DaniceYequay Chou, Bethany J. Lagrant, and Rudy E. Pinkham. 2008. Floating around Venice: Developing mobility management tool. 121208-061724. Pg. 16.

Figure 15 - Taxi Boat

Gondolas were once the primary means of transportation about the city in the 17th and 18th century before use of motorized boats became popular. However, the introduction of the *vaporetto* in 1881 presented a faster and cheaper means of transportation, which took business away from the gondoliers. This consequently turned transportation by gondola into a means of travelling for tourists looking for a traditional Venetian boat ride; they operate from early morning to late afternoon.[50] Therefore, gondolas have tendencies to slow down or even stop near tourist attractions due to this change, causing traffic and congestion on the canals.

Figure 16 - *Gondola*

As previously mentioned, the *traghetto* is an inexpensive gondola ferry that has been stripped of its decorations. *Traghetti* were once commonly used not only to cross the Grand Canal, but also to travel from island to island in Venice. Currently, these passenger boats are only used to transport people across the Grand Canal; *traghetti* stations are located at seven locations along the Grand Canal. The *traghetti* are an essential means of travel as it saves pedestrians a great deal of time from having to walk to a bridge in order to cross the Grand Canal.

Figure 17 - *Traghetto* transporting passengers across Grand Canal

A regular public transportation system serving Venice was established in 1881, using mechanically-propelled *vaporetti* boats along the Grand Canal[51]. This transport service changed owners and names

[50]Davis, Robert C., and Garry Marvin.Venice, the Tourist Maze: a Cultural Critique of the World's Most Touristed City. Berkeley: University of California, 2004. Print. Pg.140.
[51]ACTV.The history.Venice, 2009.Available from www.actv.it/en/company/thehistory.

throughout the centuries and extended its service area many times to respond to the rapid growth of the city and the need for more transportation services to accommodate this growth[52]. The area served expanded from the Grand Canal to eventually include the islands of Lido, Murano, and Giudecca, lagoon connections to Mestre, Marghera, San Giuliano, Fusina, and other mainland areas, as well as throughout all of central Venice[53]. The current company, the Venice Public Transport Company, *Azienda del Consorzio Trasporti Veneziano* (ACTV.), began operating on October 1, 1978.[54]

Figure 18 - *Vaporetto* travelling along Grand Canal

The ACTV operates 18 lines and 130 waterborne vessels.[55]One type of waterbus that the ACTV operates is v*aporetti*. They are a quick and inexpensive means of travelling around Venice, and they run continuously throughout the day making them the main method of transportation by boat along the Grand Canal and around the island. The waterbus lines have scheduled twenty-four-hour service with frequency that varies from line to line.

Figure 19 - Map of the ACTV water routes.

2.2.2.2 PRIVATE TRANSPORTATION

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[52]ibid.

[53]Fiorin, Franco, and Giorgio Miani. 1995. Development plans for urban public transport. In Cities on water and transport., eds. RinioBruttomesso, Marta Moretti, 100--107. Venice: International Centre Cities on Water.

[54]ACTV.The history.Venice, 2009.Available from www.actv.it/en/company/thehistory.

[55]Fiorin, Franco op. cit. Pg. 100-107

Private boats are not used for daily transportation because of the limited docking space available in Venice as well as the amount of work and money needed for maintenance. Instead, they are primarily used for in the summer time for leisure trips.

2.2.3 TRANSPORTATION OF CARGO

Cargo boats are the other major cause of boat traffic. Cargo transportation comprises 36 percent of Venetian boat traffic and peaks before noon because most cargo is used for restocking food and supply stores.[56]There have been recent changes to the delivery method of goods. The old system involved loading cargo boats by item and visiting each location that needed that specific good; this method proved inefficient as multiple boats were forced to travel to the same locations. Fortunately, modifications have been made to delivery methods that will significantly reduce the congestion caused by such cargo transportation.

Two teams of Worcester Polytechnic Institute students have recently completed Interdisciplinary Qualifying Projects which propose a delivery method suggesting that before cargo boats enter Venice, they report to a warehouse near the *Ponte della Libertá*, the bridge connecting Venice to the mainland. The cargo will then be sorted and shipped from this warehouse by destination, rather than by item.[57] This alternative method to coordinate shipments by location is currently being implemented and aims to reduce the number of unnecessary detours in Venice as well as the quantity of wakes.[58]This also alters traffic pattern because the cargo boats all start at the same location, and from there spread out across the city delivering goods, seldom crossing paths, and eliminating about 90 percent of the current cargo traffic[59].

2.2.4 PHYSICAL CONSTRAINTS OF BOAT TRANSPORTATION

The Venetian Lagoon is a body of water that completely surrounds the island of Venice. This lagoon is the enclosed bay of the Adriatic Sea; the tides of the Adriatic Sea directly control the water level and flows of the Lagoon as well as the city's canals. These tides affect boat traffic on the canals as boats cannot traverse the canals during extreme tidal conditions. If the tides are too low, then vessel's hull will run aground and damage the boats, whereas if the tides are too high, boats may not be able to travel under the many low arched bridges that connect the islands of the city separated by the canals.

Acqua alta is a tidal condition when tides are abnormally high, greater than 110 centimeters above sea level. This phenomenon usually occurs in the fall and winter seasons. During these conditions, boat usage can be significantly limited due to the bridges.

2.2.5 PHYSICAL CONDITIONS OF CANALS

Boats provide great mobility to Venice but also negatively impact the environment and the canals by inflicting damage upon the canal foundations with their wakes.[60]The motorized boats that are used by the

[56]Catanese, Cristopher D. op. cit. Pg. 19.
[57] Duffy, J. Re-engineering the city of Venice's cargo transportation system for the consorzitrasporativenezianiriuniti. Pg. 1-20.
[58]"Venice's Canal Delivery Traffic to Be Cut 90% With WPI Plan - WPI." Worcester Polytechnic Institute (WPI). 25 May 2004. Web. 11 Oct. 2010. <http://www.wpi.edu/news/20034/venice.html>.
[59]Catanese, Cristopher D. op. cit. Pg. 19.
[60]Catanese, Christopher D., DaniceYequay Chou, Bethany J. Lagrant, and Rudy E. Pinkham. 2008. Floating around Venice: Developing mobility management tool. 121208-061724.

A.C.T.V.'s public transportation system create wakes that have become a contributing factor in the erosion of building foundation and canal walls. Cargo ships and all other traffic also contribute to wake-induced damage to canal walls.

Starting in the 1930s, the public transportation company began testing and implementing new boat propellers to reduce wave motion and new hulls for many of the boats which significantly reduced the wave damage[61]. Recently, A.C.T.V. has been working towards improvements in the efficiency of the boats to reduce air pollutant emissions.[62] Some restructuring of *vaporetti* routes has been conducted in attempts to lessen the wake damage along the Grand Canal and simultaneously integrate the outer areas of Venice into public boating routes.[63] However, *vaporetti* routes are generally very rigid since they are limited by canal size and operate in main canals. Cargo boat routes are being adjusted as previously mentioned.

2.2.6 BOAT TRAFFIC MODELING

There have been a number of computer models created to display traffic in Venice. One noteworthy example was created by the Santa Fe Complex team. The Santa Fe Complex team, as part of the MOBILIS project in Venice led by Fabio Carrera and Stephen Guerin, created a simulation of waterborne traffic based on turn data collected by human observers at twenty-three observation points in the Venice canal system.[64] Figure 20 uses NetLogo to display a network of Venetian public transportation.

[61]ACTV.The history.Venice, 2009.
[62]ACTV.The fleets.Venice, 2009.
[63]Vittadini, Maria Rosa. 1995. The urban transport system: Transport via water and land. In Cities on water and transport., eds. RinioBruttomesso, Marta Moretti, 98-99. Venice: International Centre Cities on Water.
[64]Carrera, Fabio, and Stephen Guerin (2010) Canal Traffic Simulation – City of Venice Web.

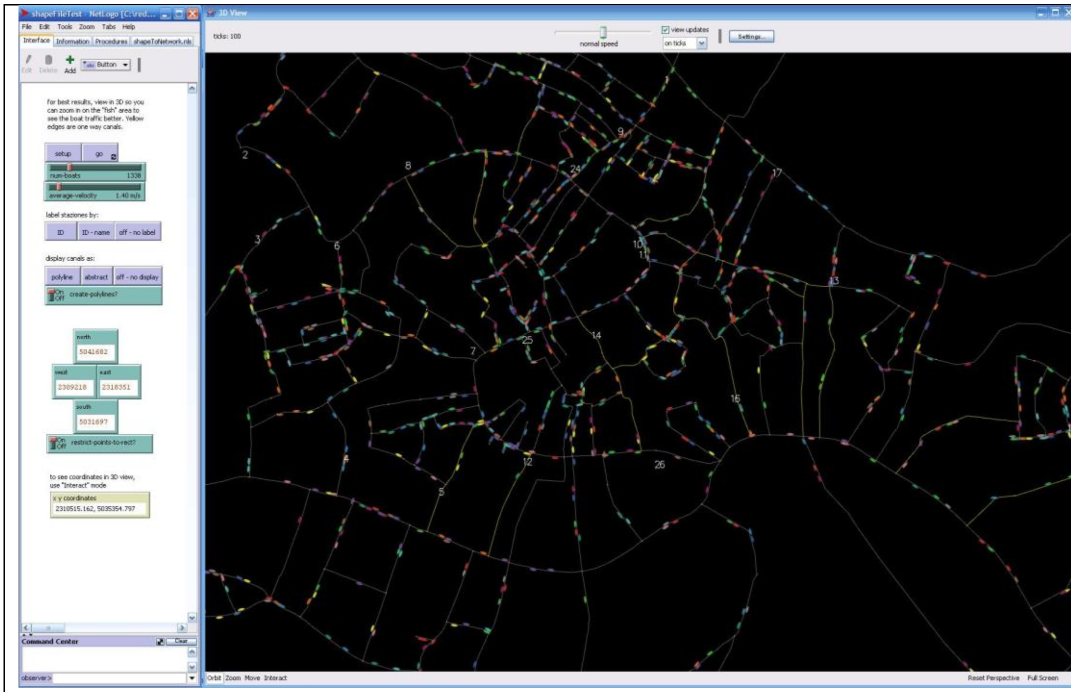

Figure 20 - Screenshot of MOBILIS Boat Traffic Model

This model uses data for each boat's turning included the time-of-day, the canal it emerged from, the canal it entered, and the boat's license number. Computer modeling gives the user the ability to visibly sort through large amount of data, with the ease of access that cannot be found by other means.

2.3 PEDESTRIAN TRAFFIC IN VENICE

Pedestrian movement is the other type of movement possible throughout Venice. This type of transportation utilizes the 160 kilometers of paved walkways throughout the city and the 450+ bridges that connect the islands. This network of pedestrian walkways can pose challenges for travelers, however, particularly those with mobility impairments, such as a cane, wheelchair, baby stroller, luggage, or personal wheeled shopping carts that many Venetians carry to transport groceries and other goods.

   

2.3.1 HISTORY OF VENETIAN WALKWAYS

As the city evolved, pedestrian walkways became increasingly important for commerce and communication within Venice. With space as limited as it is on the island, buildings are built right to the edge of the property's extent, leaving walkways incredibly narrow at times.[65]

The first walkways on the island were unpaved paths which ran between the buildings of the city.[66] The soil of the lagoon island is very poor, and the city turned to mud at the onset of rain. As the city grew and traffic increased the pathways became a constant quagmire of mud, garbage, and waste from animals. For centuries the walkways remained simple dirt paths. The first roads to be paved were the *Salizanda*, or main roads in the *sestieri*.[67] It was not until the 13th century when the remainder of the streets began to be paved with brick and later stone.[68]

Perhaps the best known of the Venetian walkways, the *fondamente* or canal sidewalks, are another important aspect of the city's infrastructure. The first f*ondamente,* like the other pathways, were unpaved and without walls which led to the constant problem of erosion. The dirt from the land along the canals would slip into the waterways which led to the need for them to be dredged quite frequently. In some cases, trees were planted along the canals banks to prevent this degradation. Eventually, the walls were reinforced with wood and later stone which firmly established the pathways built on top of them, thus giving birth to the *fondament*a we know them today.[69]

As space became more and more limited and pedestrian traffic became heavier, some of the canals were filled in, and streets were paved over them in order to expand the foot-path network and alleviate some of the demands of this higher traffic.[70] This resulted in a number of "dead-end" streets and can make the city very difficult to navigate for outsiders. These reclaimed canals are known to Venetians as *riotera*, literally "earth canal."

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[65]Ibid.
[66]1911 encyclopedia - venice. [cited November 22 2010
[67]Agenda venezia - glossary. 2008 [cited November 20 2010]
[68]1911 encyclopedia - venice. [cited November 22 2010].
[69]Ibid.
[70]Davis, Robert C., Marvin, Garry R. 2004. Venice - the tourist maze. Los Angeles: University of California Press.

Horses were very prevalent in the early days of Venice and were the preferred method of transportation for nobility.[71] As the city grew, horses became to be more of an issue for mobility rather than a solution. They caused a great deal of damage to the unpaved pathways of the time, especially for *fondamente*, and the presence of the large animals greatly contributed to the growing congestion in the city. Sanitation was another major factor, and the presence of the reeking stables did not fit well with a trading community. The introduction of stone bridges spelled the end of the use of horses in Venice, as they were unable to climb the steps of the new bridges. In 1392 a law was enacted forbidding horse traffic in certain areas of the city, much to the displeasure of the majority of the population, and the remaining animals were also required to wear bells to warn pedestrians.[72] After horses were outlawed, *gondole* became the predominant method of transportation.[73]

2.3.2 HISTORY OF VENETIAN BRIDGES

Bridges are another key part of how the City of Venice moves. With the city being a collection of islands, the bridges are essential for the unity of the city. Borne from sheer necessity, bridges have become true symbols of Venice.[74]

Bridges were in fact the last addition to the main infrastructure of Venice. For many years the only way to cross the canals was by boat or wooden planks put up by property owners. Eventually, sloped wooden bridges were constructed, but they were not an adequate solution due to frequent collapse.

Figure 21 - An example of a *pontestorto* or "crooked bridge."

[71]Rick Steves. Seeing venice via gondola. 2009 [cited November 20 2010].
[72]1911 encyclopedia - venice. [cited November 22 2010].
[73]Rick Steves. Seeing venice via gondola. 2009 [cited November 20 2010].
[74]Contesso, Lia. 2010. Venice bridges. 2010 (October 9).

The first account of a stone bridge is mentioned in an administrative document from 1170, yet the majority of the stone bridge construction took place in the 13th century.[75] Throughout the city there are a number of *pontestorto* or "crooked bridges," which join roads located at odd locations along the canals. This is a frequent reminder that bridges were built in the city long after the roads and islands had already been established.

Crossing the Grand Canal posed the biggest obstacle for pedestrians in the city's early days. In 1175, the canal was first spanned by a pontoon bridge at location of the modern day *Ponte di Rialto*.[76] The pontoon bridge was later replaced by a fixed bridge in 1265, which ultimately collapsed.[77] The *Ponte di Rialto* we see today was built in 1588.[78] The Rialto Bridge stood as the only span over the Grand Canal until 1854 when the *Ponte dell'Accademia* was built.[79] Four years later, an iron bridge was erected by the Austrian occupiers of the city at the site of the *Ponte degli Scalzi*.[80] The Scalzi Bridge we see today was built in 1932.[81] Most recently, the *Ponte della Costituzione* was built over the Grand Canal in 2008, linking *Piazzale Roma* to the Santa Lucia Train Station.[82] Today, these are the only four bridges over the Grand Canal compared to the few hundred bridges connecting Venice's other islands.

As the city continued its trade systems throughout the centuries, a bridge became necessary to connect the island city to the mainland of Italy. This strengthened the city's economy by allowing it to act as a port city.[83] In 1846 a railway bridge connecting the two areas was constructed, followed by a parallel road bridge allowing motor vehicle access to Venice in 1933.[84] These bridges integrated the historic center of Venice with the mainland, creating great economic and business ties[85]. Though these bridges allowed new types of transportation into the city, once within floating city of Venice, there remain only two means of transportation: boat or pedestrian.

In modern times, bridges fulfill another important role in the city in addition to being means of travel. Contained within or attached alongside are lines and piping connecting utilities to the separate islands of the city. Added throughout the 20th century as the city began to modernize, gas, electricity, telephone, and water lines make their way throughout the city and over canals thanks to the bridges.[86]

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[75]1911 encyclopedia - venice. [cited November 22 2010]. Available from http://www.1911encyclopedia.org/Venice.
[76]Contesso, Lia. 2010. Venice bridges. 2010 (October 9).
[77]Ibid.
[78]Ibid.
[79]Ibid.
[80]Ibid.
[81]Ibid.
[82]Cessi, Roberto and Foot, John.Encyclopaediabritannica online. "Venice". [cited October 9 2010]. Available from http://www.britannica.com/EBchecked/topic/625298/Venice/24379/Canal-boats-and-bridges.
[83]Baroncini, Alfredo. 1995. Port and urban transport developments in Venice. In Cities on water and transport., eds. RinioBruttomesso, Marta Moretti, 110-113. Venice: International Centre Cities on Water.
[84]Ibid.
[85]Ibid.
[86]http://venipedia.org/index.php?title=Bridges

2.3.3 PHYSICAL CONSTRAINTS OF PEDESTRIAN WALKWAYS

Figure 22 - A narrow walkway

Pedestrian walkways in Venice are often narrow, typically 3-10 meters but sometimes as narrow as 1 meter or less.[87]

Bridges have stairs ascending and descending that travelers must climb, which can be challenging for individuals with any mobility impairments. Any slowed movement within this narrow walkways or over bridges can cause congestion and buildup further back in the walkway.

There are very few straight streets of any length; most bend and curve and make pedestrian travel quite confusing [88], like a labyrinth that disorients travelers. [89] Many pathways also end in dead ends, as shown in blue on the following map of the city.[90]

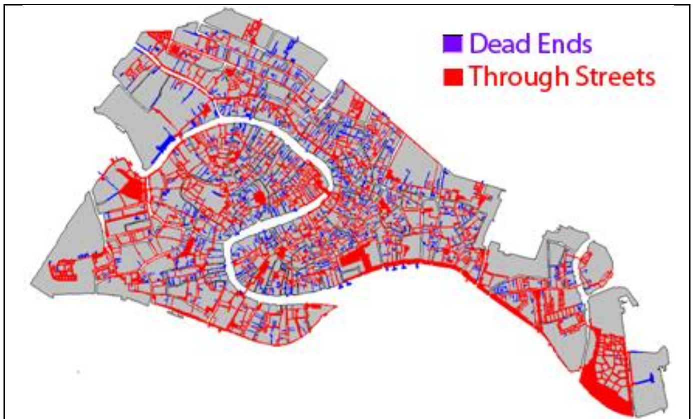

Figure 23 - Dead ends throughout the city

Figure 24 - *Plateatici* infringing into a walkway

Another physical constraint is the population of public space by vendors, restaurants, and other entities. These *plateatici* which extend into pedestrian walkways are taxed by the Venetian government.[91] This regulation places an incentive on keeping the already narrow streets and squares relatively open while still encouraging business for the vendors, but pedestrian flow is still significantly affected by these obstacles.

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[87] Davis, Robert C., Marvin, Garry R. 2004. Venice: The Tourist Maze. Los Angeles: University of California Press.
[88] Howard, Deborah, and Quill, S. 2002. The architectural history of Venice. Singapore: B.T. Batsford, Ltd.
[89] Rizzi, Paolo qtd. in Davis, RobertC., Marvin, Garry R. 2004.Venice: The Tourist Maze.
[90] Davis, Robert C., Marvin, Garry R. 2004. Venice: The Tourist Maze. Los Angeles: University of California Press.
[91] Carrera, Fabio. 2006. Street performances: The role of visual analysis in the micro-zoning of public space in Venice, Italy.

2.3.4 PHYSICAL CONDITIONS OF PEDESTRIAN WALKWAYS

The outstanding numbers of tourists and other pedestrians who travel through the city on foot every day create strain upon the city's physical infrastructure. Compounded by the weathering effects of nature, both *calle* and bridges suffer from this overuse and heavy weight demands, and can experience sinking and erosion. This can create mobility restrictions and dangers that affect travelers when the infrastructure is damaged.

Figure 25 - A pedestrian *calle* with uneven paving stones in need of repair

Depending on the level of use and the particular soil composition of the foundations the walkways were built upon, the large stones that pave *calle* have sunk unevenly and now have uneven dips and cracks in them.[92] The plaster of bridges in particular has deteriorated from humidity and weather as well as use.[93] This necessitates continual repair and temporary road obstructions during these repairs.

Figure 26 - Venetian steps and walkway being eroded by saltwater of canals lapping against them

In addition to this type of pedestrian erosion that many major tourist cities can be expected to suffer from, Venice's infrastructure also is victim to tidal erosion as the Adriatic Sea cycles in and out of the city.[94] When the city was originally founded, freshwater rivers flowed through the lagoon and purged the city's sewage which was deposited into the canals directly. However, because of the redirection of rivers and alteration of the lagoon's ecosystem over the centuries, freshwater flows through the lagoon have decreased dramatically.[95] Now, canal water is nearly as saline as the Adriatic Sea itself.[96] This saltwater erodes building foundations as it laps against canal walls and also erodes pedestrian walkways during frequent flooding events.

To perform the necessary repairs and provide ongoing maintenance to the city's infrastructure, the city of Venice formed Insula, a company dedicated to engineering and implementing the necessary repairs to preserve the city's functionality.[97] Insula works to restore bridges by consolidating foundations and replacing portions of bridges that are unstable.[98] Streets are repaved and in some cases, raised up to 120 centimeters to

[92] Insula SPA. Insula: A future for Venice. Venice, 2008
[93]Ibid.
[94] Scearce, Carolyn. 2007. Venice and the environmental hazards of coastal cities.
[95]Ibid.
[96] Ibid.
[97] Insula SPA. Insula: A future for Venice. Venice, 2008
[98]Ibid.

reduce the effects of flooding when the areas being repaved are particularly low-lying.[99] This steady schedule of construction frequently affects pedestrian mobility, forcing detours or restricting the available space for movement. Ultimately though, pedestrians will benefit from improved and safer passageways.

2.3.5 EFFECTS OF FLOODING UPON PEDESTRIAN TRAFFIC

For centuries, Venice has experienced minor flooding due to the normal tidal cycle of the Adriatic Sea. Minor flooding of a few centimeters above walkways typically goes away within a few hours with the tide.[100] These tidal effects are worst during the fall and winter and can in some cases cause *acqua alta*, particularly high tides resulting in a water level higher than normal.[101] Flooding above a 110 centimeters above sea level mark is referred to as *acqua alta*. At this height, 14% of the city is flooded.[102]

To allow pedestrians to still travel during flooding events, temporary wooden walkways called *passerelle* are assembled at a height of 120 centimeters.[103] If flooding goes above this level, the planks may float to some degree but past 140 centimeters of water above sea level, the wooden walkways are no longer effective.[104] Low-lying areas of the city are more susceptible to flooding, such as St. Mark's Square, a major tourist attraction that causes great inconvenience when flooded. Extensive *passerelle* networks are assembled throughout St. Mark's Square, but adjacent areas without *passerelle* pose challenges to pedestrians without boots and can cause major route disruptions and alterations.

Figure 27 - *Passerelle* assembled in St. Mark's Square

This flooding is primarily caused by the slow subsidence of Venice due to the weight of the islands and the rising of the Adriatic Sea.[105] Subsidence was increased in the 20th century as groundwater and methane were pumped from the ground for local industrial use, lowering the water table and increasing sinking, but this practice was stopped in 1970 and sinking has decreased to a slow rate of 0.4 millimeters per year.[106] The Adriatic Sea is rising at a rate of 1.6 millimeters per year.[107] These two opposing factors cause increasing incidences of flooding. The moon's cycle and meteorological factors contribute to the range of water levels throughout the months and year.[108]

The worst flooding in Venetian history occurred in November of 1966, when the city experienced floods of 2 meters.[109] After this dramatic flooding event, the city received great national attention and

[99] Ibid.
[100] ItalyHeaven. Acqua alta: High water and floods.
[101] Citta di Venezia. Acqua alta (high tide).
[102] Citta di Venezia. The flooding percentage.
[103] ItalyHeaven. Acqua alta: High water and floods.
[104] Ibid.
[105] Brehm, Denise. 2002. Venice could provide gateway to 21st-century flood control method.
[106] Ibid.
[107] Ibid.
[108] ItalyHeaven. Acqua alta: High water and floods.
[109] Ibid.

concern about the causes of this flooding and the city's ability to endure future flooding. Since the pumping of underground resources was found to be a major cause of increased sinking, this practice was ceased and the city recovered 20 millimeters of height.[110] However, high rates of flooding into the 2000s indicated that further methods would need to be taken to protect the city from the persistence of flooding.[111]

To respond to this need, the Modulo Sperimentale Elettro-meccanico (MOSE) project has begun construction of mobile gates to help actively protect the city from high water events.[112] These gates will be located at the three inlets to the Adriatic Sea, as seen in Figure 28, and can be raised as needed during high water instances to limit the amount of water allowed to flow into the city.[113] The gates will be used to prevent more than 110 centimeters of water from flooding the city.[114] For the majority of the year, these gates will not be raised and the normal, daily tidal flow into and out of the city will continue unrestricted.[115]

Figure 28 - Map of the three inlets of the MOSE project

2.3.6 TYPES OF PEDESTRIANS

With tourist populations often times as significant as local Venetian populations, we must recognize that these different groups have widely different destinations they travel to and styles of movement. While tourists focus on visiting as many historical, cultural, tourist attractions as possible during their often limited time in Venice, it is important to recognize that Venetian citizens live and work in this city that functions as their home. They therefore try to avoid tourists as much as possible in order to help minimize the traffic they must incur daily as they rush to work, to school, to appointments, to the markets, and to other daily, residential areas. To fully understand pedestrian mobility throughout any city, we must take these differences into account.

[110] Scearce, Carolyn. 2007. Venice and the environmental hazards of coastal cities.
[111] Ibid.
[112] Ministry for Infrastructure and Support: Venice Water Authority. Activities for the safeguarding of Venice and its lagoon. Venice, 2008
[113] Scearce, Carolyn. 2007. Venice and the environmental hazards of coastal cities.
[114] Ministry for Infrastructure and Support: Venice Water Authority. Activities for the safeguarding of Venice and its lagoon. Venice, 2008
[115] Scearce, Carolyn. 2007. Venice and the environmental hazards of coastal cities.

Figure 29 - A location tourists are likely to travel to

Figure 30 - A location Venetians are likely to travel to

Venetians typically travel to work or school between 6 and 9 in the morning and remain there until lunchtime, when they return home for the remainder of the day. Since the average Venetian retirement age is 65,[116] this schedule applies to a large portion of the population. These Venetians are forced to travel through less crowded back routes to reduce the time to commute, sacrificing the more major routes along tourist attractions to the tourists. Highly touristed routes with close proximity to major tourist attractions are shown in Figure 31.

This can also apply to boats used; Venetians opt to walk many times since waterbuses are crowded with tourists less inclined to walk through the maze-like city. Tourists, on the other hand, typically flood to housing or to major tourist attractions once they enter the city. Their interests are very different than residents. Interactions between these two major groups of individuals within the city affect mobility efficiency.

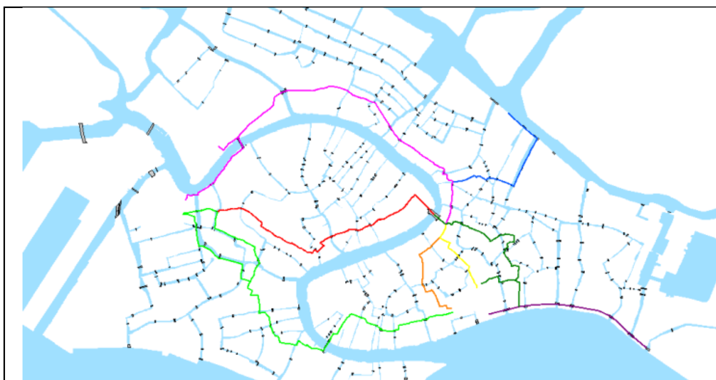

Figure 31 - High touristed routes

2.3.7 PEDESTRIAN TRAFFIC MODELING

Pedestrian monitoring is a necessary procedure that is carried out in cities worldwide in order to understand pedestrian behaviors and traffic flows so that people can navigate the streets and walkways safely and efficiently. In other cities, the planes of different means of transportation often intersect, which can make travelling very hazardous. However, in Venice, there is an ideal separation of planes for the pedestrian and boat transportation, which reveals the possibility for extremely efficient pedestrian travel if pedestrian monitoring is implemented in the city.

[116] Panteli, Chris. 2010. Italy raises retirement age by three years. Global Pensions

2.3.7.1 PREVIOUS PEDESTRIAN STUDIES

WPI has been studying the city of Venice for over 20 years, however not much focus has been placed on pedestrian traffic studies. One past study on pedestrian traffic was conducted in 2008 as part of an Interactive Qualifying Project in which pedestrians travelling through *Campo San Filippo e Giacomo* were monitored and characterized to determine how pedestrians behave in Venice. This *campo* was strategically chosen because it was the largest *campo* the group could monitor due to the team's size and time constraints. Also, *Campo San Filippo e Giacomo* contains *plateatici, and* is a relatively popular square to both tourists and Venetians. The team decided to video record the *campo* because it is the most accurate method of monitoring pedestrians[117] and would provide them with all of the necessary data; they collected data on pedestrian volumes in the *campo*, frequently traveled paths, and speeds of traffic.

Three cameras were used to capture all pedestrian traffic flow through the *campo*. The team took 15 minute simultaneous videos with the 3 cameras at the beginning of each hour from 7:00-21:00 on one weekday and one weekend day; 15 minute videos are the traffic monitoring standard.[118] The 45 minutes in between each recording was used to download the videos. These videos helped the team assess when the maximum and minimum traffic flows the *campo* as well as the common paths taken.

Figure 32- Map of Campo San Filippo e Giacomo[119]

[117] Burden, Amanda M. New York City Pedestrian Level of Service Study Phase 1.
[118] Kutz, M. Handbook of Transportation Engineering.
[119] Catanese, Christopher D., Danice Yequay Chou, Bethany J. Lagrant, and Rudy E. Pinkham. 2008. Floating around Venice: Developing mobility management tool. 121208-061724. Pg. 38.

2.3.7.2 PAST PEDESTRIAN MODELS

Since pedestrian traffic within Venice has been studied relatively recently, there are a limited number of models that simulate pedestrian traffic flow. Disruption of pedestrian traffic flow in Venice is usually caused by multiple factors: people (such as disoriented tourists) blocking passageways, overcrowding, outdoor merchandise stands, café tables, etc. or public spaces that are occupied by other obstacles such as a phone booth.[120]

The pedestrian traffic model of *Campo San Filippo e Giacomo* includes obstructions present in the square, such as *plateatici*, merchandise stands, the newspaper stand and the well in the center of the square. The model agents were programmed as either a Venetian or a tourist, and were represented by a .5 m-diameter circle. The Venetian agents move at the average speed of typical Venetians, 1.45 m/s, and tourist agents move at the average speed of small groups of tourists, 1.12 m/s.[121] The model simulates traffic at 13:00 on Wednesday. Due to lack of programming knowledge among the team and limitations of NetLogo no other traits were included.

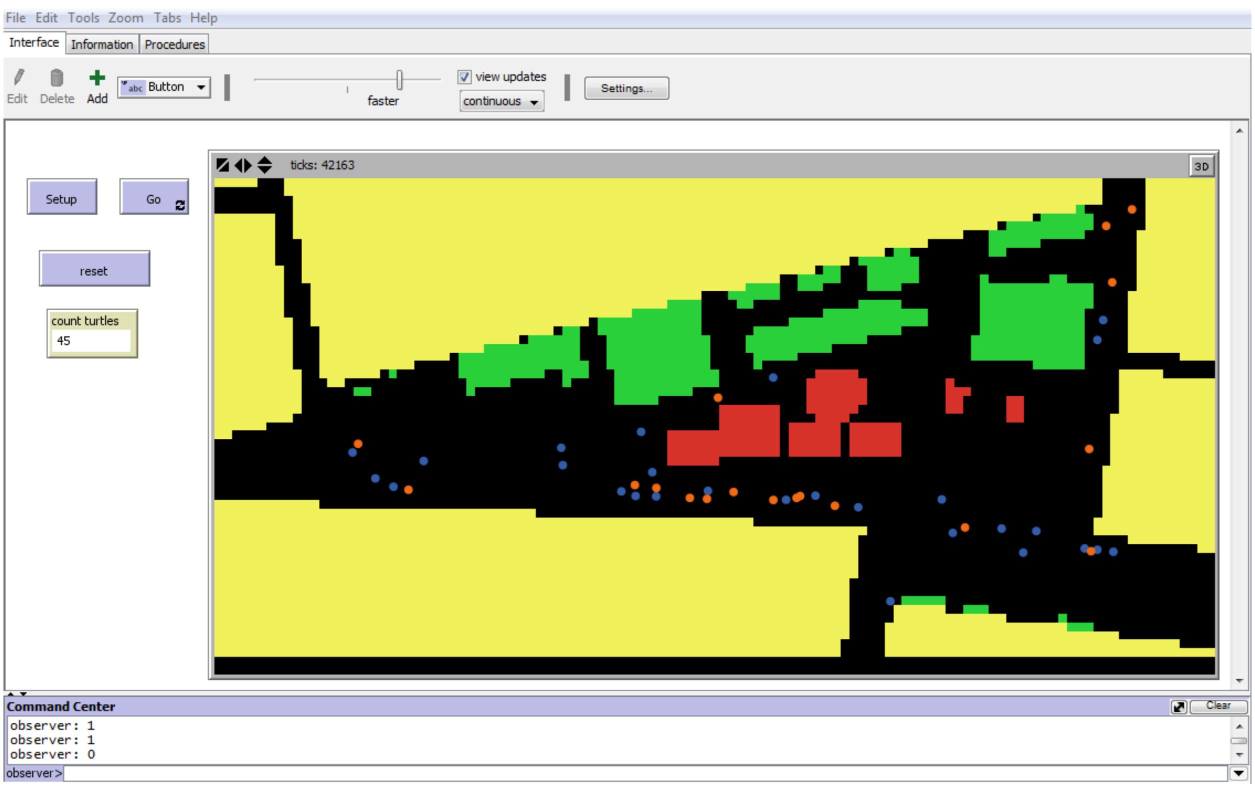

Figure 33 Screenshot of pedestrian traffic flow NetLogo model for *Campo San Filippo e Giacomo*

[120] Ibid. Pg. 36.

[121] Ibid. Pg. 51.

The interactions between pedestrians accurately simulate those observed in *Campo San Filippo e Giacomo* and agents avoid obstacles. The paths they use are the paths used by pedestrians in the videos.

There were a few shortcomings in terms of completely accurate representation of pedestrian movement through the square, however. In the model, no agents stop or slow down in the square near the various tourist stands and booths, both of which were frequent occurrences observed in the *campo*. The model agents also do not travel in groups, when in reality groups cause the vast majority of traffic flow problems in the *campo*. In fact, no traffic back-ups are shown in the model, which occur regularly *Campo San Filippo e Giacomo*.

2.4 TYPES OF MODELING

The advancement in technology has led to the birth of many different types of modeling. Flow modeling is a type of agent-based modeling which can accurately display traffic and boat patterns. As population densities increase worldwide, having a tool to construct effective evacuation methods is critical. Recent examples demonstrating the need for evacuation models include the panics in Harare, Zimbabwe, and at the Roskilde rock concert in Denmark.[122] The frequency of such disasters seems to be increasing as growing population densities combined with easier transportation systems lead to greater numbers of mass events such as concerts, sporting events, and demonstrations.[123] Understanding traffic patterns and having the capability to reorganize how pedestrians flow through a given area can reduce the possible dangers and risks of such disasters. Flow modeling has been used to understand cases such as the aforementioned evacuation occurrences.

Autonomous agent models are another form of sophisticated computer modeling. Understanding the term "autonomous" gives insight into what are the capabilities. Autonomous agents possess self-governing rules which allow them to make their own decisions based on their environment and the biases and responses they have towards this environment.[124]The flowchart below describes the intelligent process that each agent steps through when interacting with their environment.

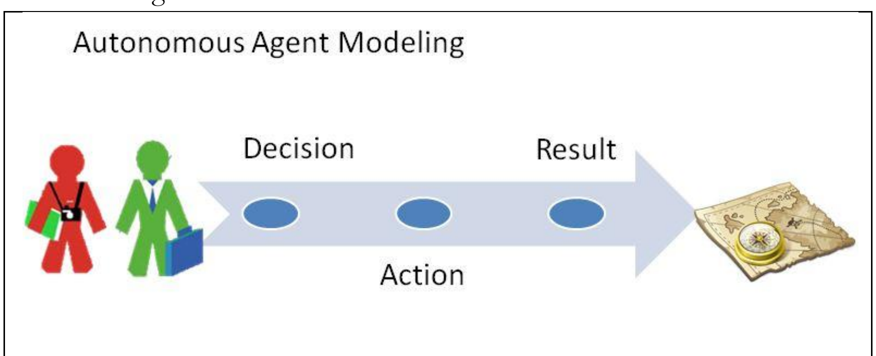

Figure 34 - Flowchart of Autonomous Agent Mindset

[122]Bonabeau, E. (2002) Agent-based modeling: Methods and techniques for simulating human systems pg. 7281
[123] Ibid. pg. 7281
[124]Dignum, F. (1999) Autonomous agents with norms pg. 69

Every agent within the model choose a goal, acts on their environment based on preferences, all towards the ultimate goal of reaching their predetermined destination in the case of traffic modeling. Though the autonomous behavior of agents can often be misconstrued as random movement, the goal of creating autonomous agents is to create realism by allowing the agents to select their own movement patterns based on situations as they arise in the environment. The accuracy of a traffic flow model is directly proportional to the ability of one's agents emulate their real-life counterparts. For example, let us consider a fire escape situation in a confined space: a movie theatre or a concert hall. Let us assume that there is one exit available. If we can realistically predict the areas with the highest density of agents, a clear path from that area can be drawn to the exit.[125] This proves that while one cannot perfectly model the behavior of each individual human agent, it is possible to understand agents' responses to environmental situations enough to benefit the community.

2.5 SMART-PHONES AND NAVIGATION

As society has become more mobile, the need to travel efficiently grows in importance. Currently, there are a number of navigation tools widely available to assist travelers: GPS devices for automobiles, websites that offer travelling directions, and more recently, specific navigation aid smart-phone applications.

Smart-phones are a subset of the mobile phone market that feature increased computing abilities in addition to their communication functions. [126] Smart-phones allow the user to not only use telephone functions, but also connect to the internet and perform a number of other tasks.[127] While it is difficult not to notice the wide spread use of mobile phones in general, the past few years have seen a profound growth in smart-phone usage. Currently 20% of the mobile phones in use are smart-phones, and this trend is expected to continue to the point where smart-phones will be the standard form of mobile communication device.[128]

Smart-phones already have the capability and computing power to run navigation applications.[129] With people able to pinpoint their exact location through the use of GPS satellites linked to their mobile device, there are numerous possibilities for navigation based tools.[130] This has profound effects on mobility, and has the capability to grant people instantaneous access to information wherever they might be.

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[125] Ibid. pg. 69
[126] Cassavoy, Liane. What makes a smart phone smart? 2010 [cited December 10 2010]. Available from http://cellphones.about.com/od/smartphonebasics/a/what_is_smart.htm.
[127] Entner, Roger. Smartphone to overtake feature phones in U.S. by 2011. 2010 [cited December 10 2010]. Available from http://blog.nielsen.com/nielsenwire/consumer/smartphones-to-overtake-feature-phones-in-u-s-by-2011/.
[128] Ibid.
[129] Hill, Simon. Best iPhone navigation apps. 2010 [cited December 10 2010]. Available from http://www.brighthub.com/mobile/iphone/articles/80320.aspx.
[130] Ibid.

3. Methodology

The goal of this project is to improve mobility efficiency in the historic center of Venice by evaluating pedestrian traffic and developing tools to be used by individuals and city planners to facilitate daily travel and visualize pedestrian movement throughout the city as a whole.

Project Objectives:

1. To evaluate pedestrian traffic in the historic center of Venice by counting at critical flow points.
2. To visualize how the city moves by creating a computer model of pedestrian traffic.
3. To facilitate individuals' daily travel by creating a navigation aid smart-phone application specifically incorporating public transportation.

This project focused on pedestrian traffic within the city of Venice. A great deal of data on boat traffic has been collected by previous groups and incorporated into a computer model, whereas relatively little study has been conducted on pedestrian traffic. With the ultimate goal of studying and improving mobility throughout the entire city, this team has focused upon the district of San Marco. Since this is a central district, connects to two of the bridges across the Grand Canal, features the primary tourist attraction of St. Mark's Square, and is the overall most touristed of Venice's six districts, this was a critical area to study to gain immediate information about mobility in the most congested areas of the city. The adaptation and extension of this team's counting methodology to the rest of the city will create a thorough understanding of Venetian pedestrian mobility.

The team's observations were limited to a 7-week stay in Venice, from October to December, 2010; a limited time frame which cannot provide accurate insights for the city's mobility during other months of the year. Venetian mobility is certainly different in different seasons, particularly the summer tourist seasons, and around holidays such as Carnivale. To account for this, the adjustability of the computer model to continually accept supplementary data is a key feature which renders it highly valuable.

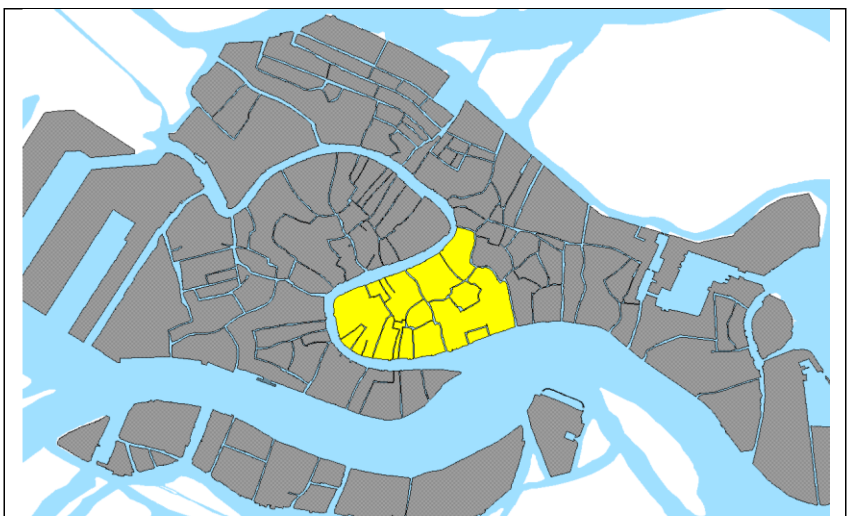

Figure 35 - San Marco focus area

3.1 QUANTIFYING PEDESTRIAN MOBILITY

Our team created a systematic collection method for quantifying the movement of pedestrians through the city. The focus area of our data collection was the San Marco district. Using an organized counting method and determined high traffic counting locations, our team evaluated pedestrian traffic flow and mobility.

3.1.1 FOCUS AREA AND COUNTING LOCATION CHOICES

Individuals in Venice can travel between islands in only three ways: by crossing a bridge between adjacent islands, by traveling on a boat that brings them between islands, or by traveling on a ferry across the Grand Canal, called *traghetti*. Therefore, it is these three critical flow points that act as bottlenecks for traffic between islands and can provide insight into routes individuals take from source to destination. This team selected 10 high volume bridges within the district of San Marco and the 5 *vaporetto* stops within this district to gather pedestrian data for, since these two represent the major means of transportation for individuals in Venice. *Traghetti*, a minor form of transportation, can be studied in the future to supplement this data. The focus area and methods for determining which bridge locations to perform counts at changed throughout the execution of this project. For a full explanation of these changes of locations, see Appendix C.

3.1.1.1 BRIDGES

The team collected data on 10 bridges based on their overall volumes of pedestrians crossing throughout the day. A map of tourist pathways (*grafopedonale*), as considered by the city of Venice, that travel close to tourist attractions and entrances to the city was consulted to determine highly touristed routes and bridges along these routes. Overlap between the map of tourist pathways and major routes on tourist maps reinforced the perception that highly touristed pathways directly translate to high traffic volume routes in this city of nearly a 1:1 ratio of tourists: Venetians on a typical day (59,000:60,000). Ten bridges were selected along these routes, throughout the district, including the two bridges crossing the Grand Canal connecting to the district of San Marco: Ponte di Rialto and Ponte dell'Accademia. See Table 1 for the full list of the bridges selected, and Figure 36 for their locations.

Table 1 - Ten Selected High Volume Bridges

# on Map	Bridge Name	Bridge Code	Canal Crossed
1	Ponte del'Ovo	LOVO	Rio de S. Salvador
2	Ponte del Bareteri	BARETE	Rio dei Bareteri
3	Ponte della Canonica	CANONI	Rio de la Canonica o de Palazzo
4	Ponte della Paglia	PAGLIA	Rio de la Canonica o de Palazzo
5	Ponte dei Fuseri	FUSERI	Rio dei Fuseri
6	Ponte de le Ostreghe	OSTREG	Rio de l'Alboro o de le Ostreghe
7	Ponte dell'Accademia	ACCADE	Canal Grande
8	Ponte Sant'Angelo	FRATI	Rio de S. Anzolo
9	Ponte di Rialto	RIALTO	Canal Grande
10	Ponte Sant'Antonio	ANTON2	Rio de la Fava

Figure 36 - Map of the 10 bridges counted in the San Marco district

3.1.1.2 VAPORETTI

The public transit *vaporetti,* or "waterbus," system is an integral part of Venetian mobility. If individuals are travelling by boat it is extremely likely that they will be using the *vaporetti* system. Private boats and taxis are less heavily used for daily travel and both exhibit random movements that would be more difficult and less significant to record than the scheduled, repetitive routes of *vaporetti* boats that transport large numbers of individuals every day. Their random behavior also makes them irrelevant for study in the terms this team is considering. The team utilized *vaporetti* ridership data available from the ACTV that specified the number of individuals boarding and disembarking at each boat stop run by the ACTV for one 24-hour period (See Appendix D). Since there are five boat stops located along the Grand Canal connecting to the district of San Marco, our team extracted the available ridership data for these boat stops. Table 2 includes the boat stops located in San Marco as well as the lines that service them.

Figure 37 - Five *vaporetti* stop locations

Table 2 - The Five Boat Stops Servicing the San Marco District

Boat Stop Name	Location	Line(s)
Rialto	Northern San Marco; west of Rialto Bridge	1, 2, N
Sant'Angelo	Northwestern San Marco	1
San Samuele	Western San Marco; south of Sant'Angelo	2, N
Santa Maria dei Giglio	Southern San Marco; east of Accademia Bridge	1
San Marco-Calle Vallaresso	Southern San Marco; west of St. Mark's Square	1, 2, N

3.1.2 DISTINGUISHING TOURISTS AND VENETIANS

Figure 38 – A mechanical clicker used for counting pedestrians

When performing counts of pedestrians, the primary distinction to be made was between tourists and Venetians. This critical distinction was based on visual appearance and observable behavior within a brief time period as the individual walked over the bridge—a less than 30-second event. We could not survey individual pedestrians to ascertain if they were residents of the city or visitors during real counting sessions; therefore it was critical to be certain our distinctions were accurate and standardized among group members so that all data would be compatible and representative.

To learn to make these distinctions, we performed preliminary counts at the Accademia Bridge using mechanical clickers. During this preliminary counting session, no data was recorded. All four group members stood together on one side of the bridge, each with two mechanical clickers, and designated one clicker in one hand to count tourists and the other clicker and hand to count Venetians. We counted individuals crossing the bridge and discussed aloud our tourist or Venetian classifications and basis for these decisions. The following table was compiled to organize defining characteristics of each class. Many of these indicators are subjective and discretion was used in each case to make the most qualified decision, building upon as many observable indicators as possible

Table 3 - Tourist and Venetian Indicators

Tourist	**Venetian**
Carrying luggage or a camera; may stop to take pictures	No camera or map
Carrying or consulting a map	Walks quickly and directly; doesn't pause to look at buildings, scenery, or tourist attractions
Looking around at buildings, pointing scenery out	Has a pet or large, complex baby carriage such that would be unlikely to be taken on a plane
Looks lost or flustered	Traveling with a personal, wheeled shopping cart (bag mounted on a dolly, typically used for groceries)
Carrying shopping bags that seem to be for small trinkets or tourist items	Carrying groceries, even without a shopping cart
May be carrying a large backpack for staying places overnight	May be carrying a smaller backpack for textbooks or as a purse; May carry a briefcase
Looks at street signs/bridge signs to orient self	Carrying shopping bags that seem to be for clothes or daily supplies/non-tourist items
Generally in groups of 2+	Alone
Speaking a language other than Italian	Speaking Italian (caution, may be from elsewhere in Italy)
Non-European looking clothing (any American brands we recognize, very bright colors - for a rain jacket, for example)	Professional attire, as if they are traveling to or from work
Clearly tourist goods such as umbrella with pictures of Italian tourist attractions	Worn-looking or heavy-duty rain boots such as full leg-length boots
New, unused rain boots	Does not look up at any attractions as they walk along
	
Figure 39 - Tourist indicators	**Figure 40 - Venetian indicators**

However, some situations arose in which identifying an individual was more difficult because the individual was not identifiable by any obvious means. In those cases, the counter would follow this individual with their gaze even once the individual was past the bridge (taking care not to miss any other individuals in the meantime) and look for identifying signs. These cases occurred less than 10% of the time, but with this continued watching even past the bridge itself, nearly all cases were resolved (close to 95%). The remaining contributed to the unavoidable degree of error since interviewing each individual who was not easily identifiable would have been infeasible.

3.1.3 DETERMINING MAXIMUM PROCESSABLE DATA

Preliminary field counting was also conducted to evaluate our ability to intake large amounts of information at once—the maximum amount of data one individual could process and accurately record while keeping up with traffic and not missing any individuals. The total number of individuals crossing, even in both directions, at first seemed simple and feasible for one person to count. Preliminary practice counts distinguished tourists and Venetians from one another. This indicated it would be possible to record one direction of traffic and make the distinction between tourists and Venetians. Depending on the level of overall traffic across the bridge, it might be possible to record both directions. However, rather than risk being overwhelmed by traffic surges in which it was impossible to process all individuals, the decision was made that each team member would only focus on one direction of traffic at once. This reduced the risk of data loss if a surge of traffic went unrecorded, or was recorded incorrectly. Although the Accademia Bridge crosses the Grand Canal and was expected to have a very high traffic level, the Rialto Bridge was expected to have a substantially higher traffic level. Therefore, although we may have been able to process two directions at once for the Accademia Bridge, it would be unlikely we could process both directions of Rialto. As a result our team erred on the side of less data to be collected by one individual.

During preliminary counts our team planned on using programmable graphing calculators with more than 9 buttons which would correspond to more than 9 different attributes we would count. The final counting devices (mechanical clickers) allowed for only two possible attributes to be collected by one individual. This reinforced the decision to collect fewer attributes. See the following methodology section 3.1.4 for the full details of the selection of final counting devices.

3.1.4 COUNTING DEVICES

To collect all but one day of pedestrian counts at bridges, mechanical clickers were used by all group members. By holding one clicker in each hand, one team member was able to count two sets of data: number of tourists crossing and number of Venetians crossing in one direction.

A number of possible counting systems were investigated throughout the project, detailed in Appendices E and F, but ultimately dismissed in favor of the reliable performance and simple data output produced by mechanical clickers. A field form corresponding to the usage of these clickers is shown in Appendix G.

3.1.5 TIME BRACKETS FOR PERFORMING FIELD COUNTS

Differences in total flows and proportions of Venetians and tourists traveling through certain areas were anticipated for different times of day. As only one example to illustrate this, tourists are more likely to leave their hotels closer to 10 AM and travel to tourist destinations, whereas Venetians due at work or school for 8 or 9 AM must leave their home locations much earlier in the morning. Thus, in the early morning, Venetians will dominate travel and then represent a smaller portion of travelers in the later morning when they are at their work and school destinations.

This necessitated the use of a number of time brackets in which traffic could be assumed to be more homogenous than for the entire day. A full day of counts was performed at *Ponte Sant'Antonio* (shown in red on the map below and in a corresponding picture), identified as a high volume bridge used by both Venetians and tourists since it is located near the Rialto Bridge connecting two sides of the Grand Canal. The number of Venetians and tourists passing in each direction was recorded every 15 minutes from 6 AM until 8 PM.

Figure 41 - Map of Ponte Sant'Antonio

Figure 42 - Picture of Ponte Sant'Antonio

The data gathered led to the creation of the following time brackets:

Table 4 - Five Time Brackets

Bracket Name	Start Time	End Time
Early Morning	7:00	9:00
Morning	9:00	11:00
Mid-Day	11:00	13:00
Afternoon	13:00	17:00
Evening	17:00	19:00

Within each of these time brackets, flows still fluctuated but remained relatively stable and homogenous for both tourists and Venetians traveling in each direction. The following graph shows the total numbers of Venetians and tourists traveling in each direction, overlaid with the established time brackets. The hours 6-7 in the morning and 19-20 at night showed low levels of traffic and were left out of time brackets since more highly trafficked times of day would be more indicative of overall traffic flows.

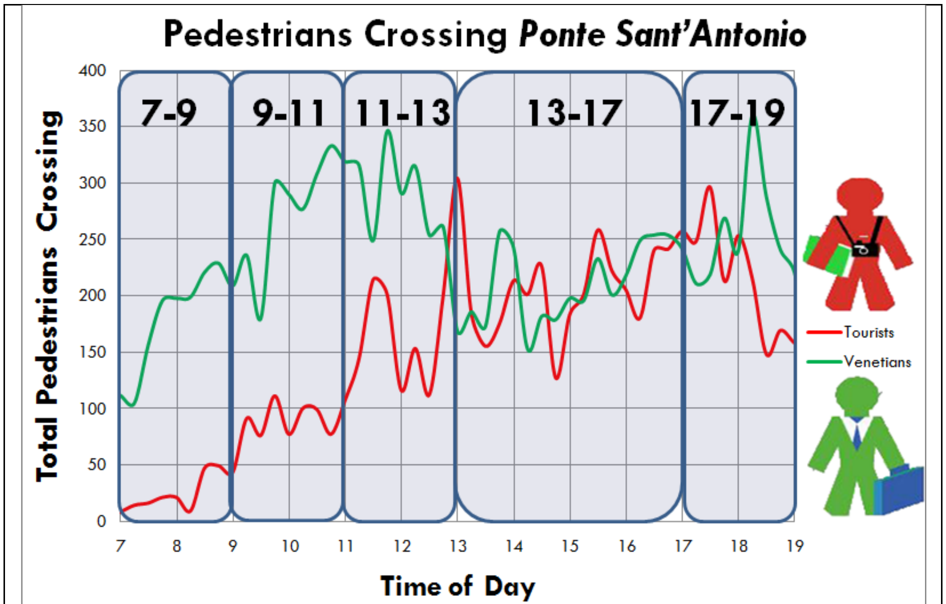

Figure 43 - Basis for time bracket divisions

These brackets create a significant level of homogeneity while maintaining a manageable enough number of time brackets. Consequently our team performed field counts within each bracket at various locations.

3.1.6 COUNTING METHODS AT BRIDGES

At each of these bridges, two team members stood facing opposite directions at the top of the bridge, each focused on one direction of traffic traveling towards them. Holding a clicker in each hand, one to count the number of tourists crossing and one to count the number of Venetians crossing, each team member would record one click using the appropriate hand to count the number of individuals crossing. This count was performed for a 15 minute time period. After the 15 minute session had ended, indicated by an alarm set on a cell phone to ensure a precise time lapse, both team members' totals of Venetians and tourists passing over the bridge were recorded. The field form used for this can be seen in Appendix G. At each bridge, traveling from one direction was designated as "coming from [a landmark]" and one as "going away from [the same landmark]". Saint Mark's Square was typically used as the identifying landmark. The specific island codes describing these directions were later identified and used to more formally describe these bridge directions. See Appendix H for summarized counts at these ten bridges.

3.1.6.1 COUNTING AT RIALTO

For Rialto Bridge, which contains three different travel lanes separated by stone walls lined with shops and six different entrances and exits, a more complex counting method was required. To capture all these lanes of traffic, all four group members were required. The following image shows the positioning of each group member and the lanes of traffic and directions each was focused on counting. Since Rialto Bridge is such a major bridge, acting more significantly as a filter point for the city than the other Grand Canal bridges do, more than one 15-minute counting session was collected to help obtain more accurate data. Two consecutive 15-minute sessions within each time bracket were collected and averaged together; the two data sets providing a basis of comparison for one another. This also allowed us to count traffic in each of the three lanes since with four counters paired together, only two lanes could be counted at once. Half-hour periods within each time bracket leading up to the peak traffic period within that time bracket were selected, based on the time brackets determined at Ponte Sant'Antonio. This corresponded to the times: 8:30-9; 9:30-10; 11:30-12:00; 15:00-15:30; and 18:00-18:30.

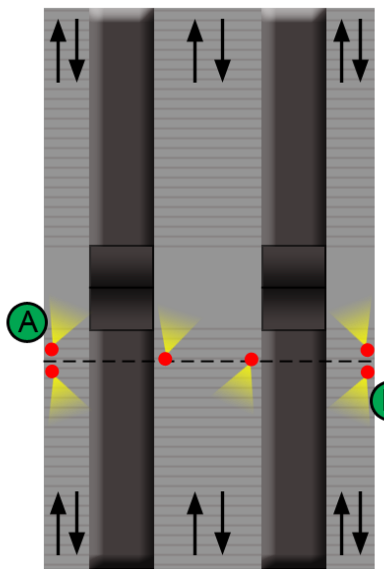

Figure 44 - Counting positions at Ponte di Rialto

As shown in Figure 44, two team members were positioned along the interior lane of traffic and collected two consecutive 15-minute data sessions, each team member counting one direction of traffic. These were averaged together to help ensure accurate counts and reinforce homogeneity of time brackets. The remaining two team members worked together to collect one 15-minute data session at one exterior lane of traffic, shown as lane A in Figure 44, immediately followed by a second 15-minute data session at the opposite exterior lane of traffic, lane B. Since these exterior lanes were observed to have lower levels of traffic, one data collection session each as opposed to two as for the interior lanes was acceptable. Each of these 15-minute data sessions on either side was taken as representative of that lane of traffic during the entire time bracket; they were not averaged as the interior lane was since counts for a total of three lanes were needed.

To calculate the total flow of passengers during a 15-minute period through all three lanes of traffic on Rialto Bridge, the total number of tourists and Venetians crossing in the two exterior lanes of traffic were summed together, with the average of the interior lane.

3.1.7 WEATHER CONDITIONS DURING FIELD COUNTS

To help ensure that our field counts of pedestrians would be representative of normal pedestrian traffic, we performed these counts on days when weather did not deter any traffic, to the best of our judgment. Heavy rain was assumed to alter routes and cause individuals to opt to take boats rather than walk. This would reduce the flows of pedestrians over bridges, and counts were therefore not performed on days with heavy rain. Days with light rain were considered to not affect movement significantly. If heavy rain occurred in the morning but stopped later in the day counts were postponed to another day. This however was not spurred by anticipated continued changes in traffic even after the rain lessened and instead happened to coincide with other time commitments.

Acqua alta also significantly alters routes, despite *passerelle* available throughout some areas of the city. Tide forecasts provided by the city were consulted before each day of pedestrian field counting. Days with predicted tides greater than 95 were treated as potentially affecting pedestrian routes. During the course of this project's data collection, all high tides forecasted were for early morning hours. Therefore, in the morning on each day we judged the tide level outside our apartments and compared visually water levels to normal water levels. If the tide was judged to be more than 110 centimeters, counts were ceased. Regardless of the exact water level (the specific level of which was not determined each day) judged by the team, if the counting location was known to be in a low-lying area of the city susceptible to flooding, counts were postponed until a later date. Based on tide forecasts, we determined the forecasted time that the water level would be at or below the normal water level of 90 centimeters, generally four hours after the predicted high tide. At this time we resumed counts.

Other weather events that were not encountered during this project but during which we would not have performed counts include extreme fog (that which significantly impairs visibility and would cause boats to stop operating or alter their routes) and snow.

3.1.8 MOBILITY IMPAIRMENTS

To reduce the amount of information recorded during bridge counting sessions into a more manageable amount, this team chose to determine average proportions of mobility impairments at a major bridge in the San Marco district and accept this data as representative of mobility impairments throughout the entire district. A project completed in 2007 by a team of Worcester Polytechnic Institute students, entitled Urban Maintenance: Assessing Venetian Quality of Life, quantified mobility impairments on the island of Tolentini in Santa Croce. We accepted their divisions and characterizations of the following mobility impairments and used these divisions when performing our counts. After completing our full day of counts for these mobility impairments, we compared our proportions to theirs, anticipating some differences in the amount of luggage carried since their counts were at bridges much closer to *Piazzale Roma* and *Tronchetto* — entrances to the city.

Ponte Sant'Antonio was again chosen as the bridge to conduct our full day of counts at. This bridge, connecting the Castello and San Marco districts serves as a major bridge used by both tourists and Venetians. Since a full day of counts of tourists and Venetians with direction was also conducted at this bridge to determine time brackets, simultaneous mobility impairment counts were conducted.

A previous methodology for recording mobility impairments is described in Appendix I.

At Ponte Sant'Antonio, the following mobility impairment types, used by the 2007 team were recorded, here with their descriptions:

MOBILITY AIDS

Handicapped individuals seen using any of the following mobility aids were counted once towards that category of impediment.

- Wheelchair
- Crutches
- Walker
- Cane

ROLLING ITEMS

Although the following are not physical disabilities, each one creates a burden for the owner when they must be transported across a bridge. Note that, each item was counted as only one impediment, regardless of the number of people required to transport it over the bridge. This was done since, usually, only one person would be required to move the item over a handicap accessible ramp.

- Stroller – both the operator and passenger of the stroller are counted towards the total pedestrians, but only count once towards the impediments.
- Luggage – rolling type luggage that was not being carried by the owner prior to approaching the bridge. Any luggage carried by the owner was not counted since these people would not benefit from the installation of ramps
- Shopping Cart – a bag mounted on a dolly that is commonly utilized by Venetians for groceries
- Delivery Cart – any dolly or cart that can be used to transport heavy or bulky packages

SUBJECTIVE CATEGORIES

The classification of individuals with the following impediments was highly subjective. In many cases, people who could be described by the following categories were unaffected by crossing bridges. As a general rule, the team only counted people falling into the following categories if they showed clear signs of duress such as heavy breathing or slow movement.

- Limp
- Elderly
- Large Parcels – any carried object: commonly large boxes, boards or oversized bags/objects
- Overweight**/Pregnant
- Other – is to be defined in the "Notes" section if a person crossing the bridge does not fit another category, for example someone with a mental disability with difficulty crossing the bridge

The frequency of these mobility impairments during 15-minute periods from 6:00-20:00 was recorded. See Appendix J for the field form, and Appendix K for the results of this 2007 project. Though the 2007 team identified 9:00-11:00 and 16:00-18:00 as peak times of mobility impairments, we recorded mobility impairments throughout the entire day to assist in determining if determining if their data would be representative of other areas of the city, specifically San Marco where our focus for this project was to be, as well as unchanged in the three years since these previous studies were conducted. See Appendix L for the mobility impairments counted.

3.1.9 LOCATIONS OF PEDESTRIANS TRAVEL

Tourists and Venetians have widely different locations they are likely to travel to throughout the day. This observation served as the basis for our division between these two groups. Further divisions into day or overnight tourists, and young, adult, or elderly Venetians were necessary to incorporate the most detail into these likely destinations throughout the day. The locations each will begin their days in the morning, locations they will travel to throughout the day, and the times they are likely travel aid in distinguishing these groups.

3.1.9.1 TOURISTS

Tourists in general travel primary between hotels, the entrances or exits of the city, and tourist attractions. Day tourists enter the city in the morning and leave at night, whereas overnight tourists spend more than one day in the city. Both travel to similar locations. Tools to determine each type of tourists' origins, destinations, and travel times are summarized in the following table:

Table 5 - Tools to Determine Locations of Tourists

	Day Tourists	**Overnight Tourists**
Origins	Tourism statistics from the City of Venice, COSES reports, *The Venice Report*	Maps of hotels (see Figure 45)
Destinations throughout the day	Maps and general knowledge of tourist attractions: museums, churches, climbable belltowers, *scuole grande*, theaters, etc	Maps and general knowledge of tourist attractions: museums, churches, climbable belltowers, *scuole grande*, theaters, etc
Times of travel	Subjective sense, consultation with advisors	Subjective sense, consultation with advisors

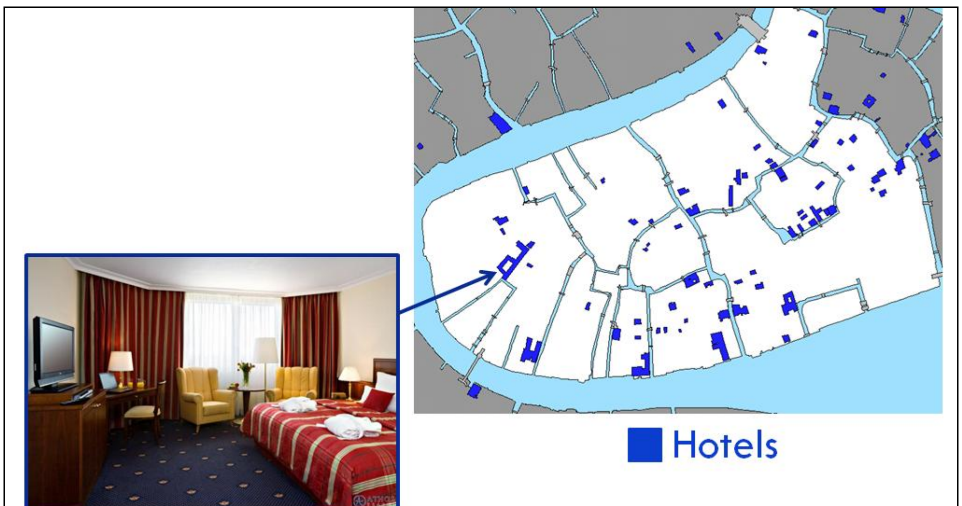

Figure 45 - Hotel locations throughout San Marco

3.1.9.2 VENETIANS

Venetians travel primarily between home locations, work or school locations. Tools to determine each age group's origins, destinations, and travel times are summarized in the following table:

Table 6 - Tools to Determine Locations of Venetians

	Venetian Youth (0-19)	**Venetian Adults (20-64)**	**Venetian Elderly (65+)**
Origins	Residency by census tract from Italian Census Bureau	Residency by census tract from Italian Census Bureau (see Figure 49)	Residency by census tract from Italian Census Bureau
Destinations throughout the day	Maps of schools	Employee totals by census tract from Italian Census Bureau (see Figure 50)	Residency by census tract from Italian Census Bureau
Times of travel	Schedules of typical schools	Schedules of typical workers	Subjective sense, consultation with advisors

Census data collected by the Italian Census Bureau during 2001 details the residency and work location distributions throughout Venice. See Appendix N for this summarized census data for San Marco.

3.2 VISUALIZING MOBILITY WITH A COMPUTER MODEL

Autonomous computer modeling allows an observer to visualize an accurate real world scenario based on the decisions of the modeling agents. The modeling agents in this case are the pedestrians we have classified. Prior to the model's conception we compiled the necessary modeling inputs. The inputs of the model include using agent characterizations, bridge data collection, and census tract data to fuel the movement of the model. NetLogo is a powerful agent-based modeling software package which allowed us to create a detailed prototype of a pedestrian mobility model's capabilities. Collaborating with the Redfish Group, we constructed an effective way to display how the different pedestrian agents can traverse Venice. Figure 46 displays a flow diagram of how the model was conceived.

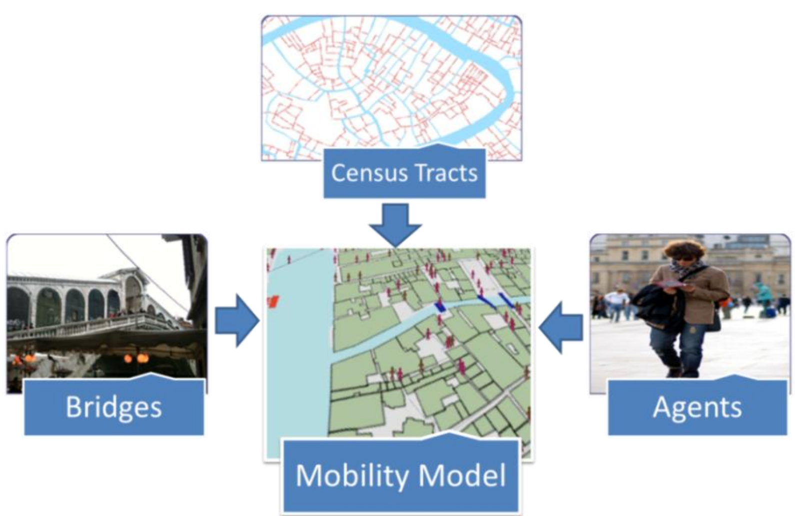

Figure 46 - Necessary Inputs for Mobility Model

3.2.1 PEDESTRIAN TRAFFIC MODELING ENVIRONMENT TECHNIQUES

The first challenge of modeling pedestrian traffic in Venice was constructing the environment the pedestrian agents move within. Accordingly our first step in developing the model was laying out the paths that the agents can take from their origin to their destination. An accurate way of creating maps is through the use of GIS, or Geographical Information System data. GIS data is a powerful way to manage and display map related information. Our team acquired current GIS maps of Venice which displayed all the walkways and bridges of the city. The map layers seamlessly integrated into the modeling environment. The benefit of using the GIS map data are that the maps are detailed, fully constructed and updateable for years to come.

3.2.2 AGENT CHARACTERIZATION

The autonomous agent model design path allows for one to create a very sophisticated model. Utilizing the autonomous aspect of our design, we created numerous distinct agent types with the goal of representing the current pedestrian demographic in Venice. The term agent refers to a hierarchy in which the subcategories will include a breakdown of the different types of pedestrians Venice contains. For example Figure 47 shows how both tourist and venetians are forms of agents that intelligently interact with the model to choose their destination.

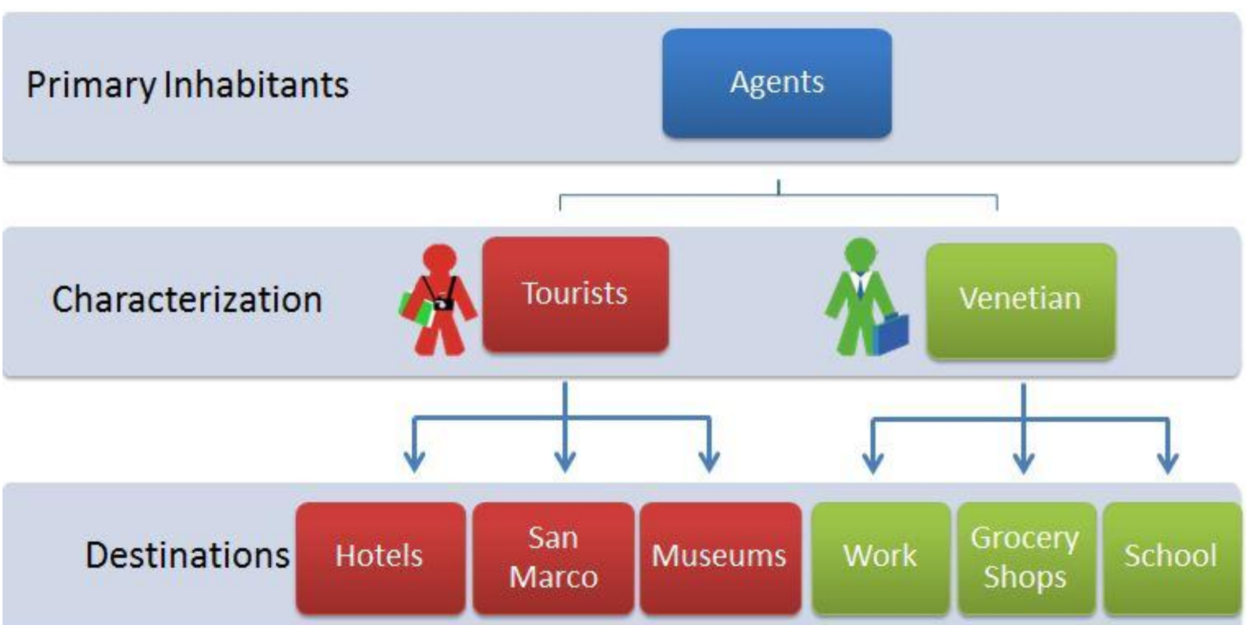

Figure 47 - Agent Modeling Sample Breakdown

In order closer approximate movement throughout the city, our team took another step towards resembling real life traffic flow. This involved developing a detail list that included seven pedestrian types:

- Venetian Youth: 0-19
- Venetian Adult: 20-64
- Venetian Elderly: 65+
- Venetian: Mobility Impairment
- Tourists: Day
- Tourists: Overnight
- Tourist: Mobility Impairment

Each of these pedestrian agent types has a breakdown of their destination and weight percentage. Each destination's weight percentage corresponds to how many agents of a given type travel there. The weights have been assigned based on tourist popularity as well as census tract information. For example a day tourist such as the one in Table 7 below, will have a 95% percent chance of entering the San Marco district over the Rialto bridge, because it is a major pedestrian path and tourist attraction. This team constructed a full trip file of the detailed agent breakdowns (See Appendices O –P).

Table 7 - Weighted Agent Destination Breakdown

Agent ID	**Agent Type**	
TDay	Tourist: Day	
Destination Pool		
Location		**Weight Percentage**
Rialto Bridge		95%
Palazzo Ducale		60%
Palazzo Mocenigo		15%

Using the trip file the model accurately provides each generated agent with an intelligent destination option, based off behavioral tendencies. The model has been designed to populate the district of San Marco with a number of agents of our choosing and intelligently send them to one of their possible destinations. As the pedestrians move towards their goal, they ultimately will cross over our data collections sites. The model can be used to validate the realism of our counts, by compiling its own data collection to compare the two.

Figure 48 displays how every pedestrian agent will have multiple trip options based on their characterization. This example is of a tourist agent starting at Rialto and whose goal is to travel to Piazza San Marco. The agent has two choices; they can travel over Ponte dei Bareteri, or Ponte dei Fuseri. The route that takes the agent over Ponte dei Bareteri has a greater number of tourist attractions. The agent recognizes this and responds by travelling down this route, thereby reacting to the environment. In doing this, the agent makes its way to its desired result.

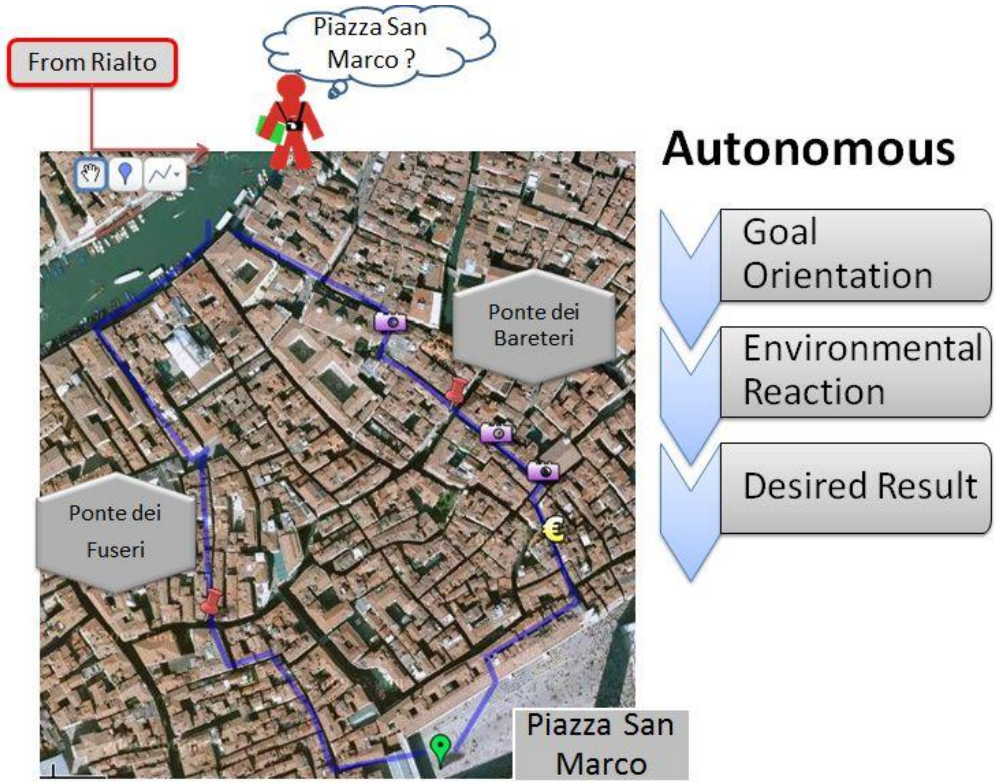

Figure 48 - Pedestrian Movement Breakdown

3.2.3 CENSUS TRACTS

The autonomous agent model includes census tract GIS map layers to complement our detailed agent breakdown. Each Venetian pedestrian agent is broken down further to better understand their origins and destinations. The census tracts layers displayed how many venetians within the three age brackets live in the sectioned off portions of Venice. Figure 49 shows the home location of adults and amounts within the San Marco area.

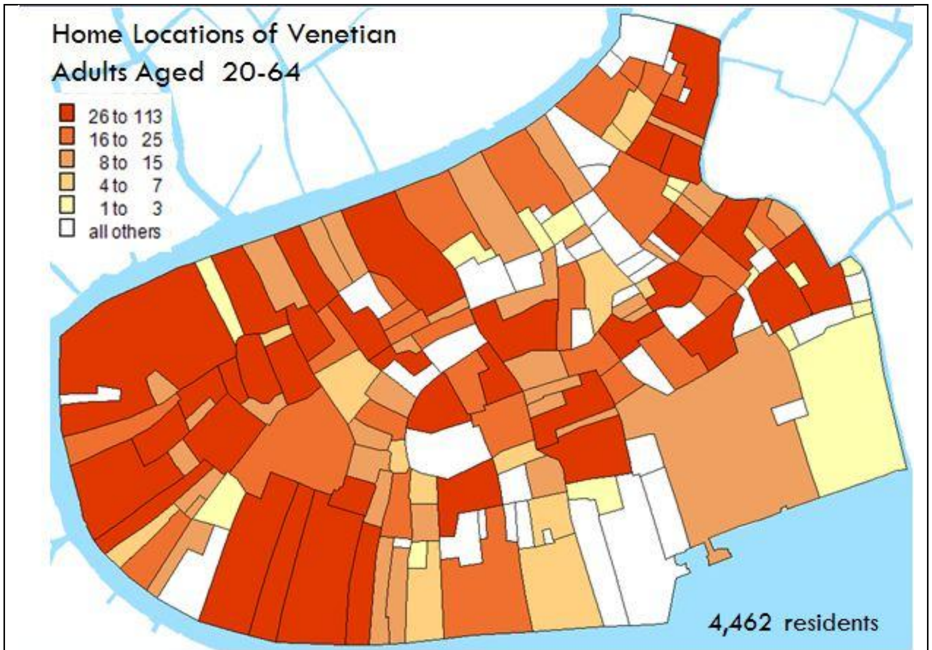

Figure 49 - Home Locations of Venetians Age: 20-64

Additionally, each age bracket possesses behavioral tendencies which distinguished themselves from each other. For example the youth (0-19) age bracket would have the majority of destination percentage include schools, in relative proximity to their residency. The census tract layer also provides the location and amount of venetians that work in a given area. Figure 50 gives an example into the work location distributions in San Marco.

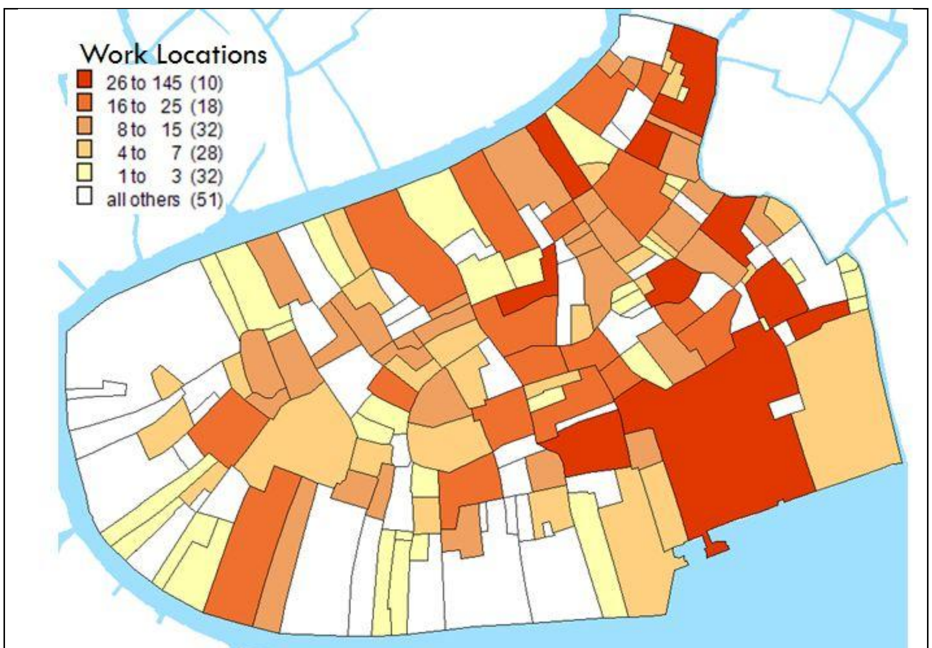

Figure 50 - Work Locations and Amounts: San Marco District

The blend of the two census tract layers allowed for the model to generate Venetian pedestrians with the real life constraints they would face every day traveling from home to work.

3.2.4 REAL-TIME MODELING

Including the time at which we collected field data for the pedestrian agents was another component other model. The data we collect at the given times of day (see Appendix) will factor into the decision each agent makes at an intersection. As the model progresses, it will account for the passing of time throughout the day. For example, if a day tourist is active from 10am to 12pm, then they will not visually appear in the 2pm layer of the model. Furthermore, each destination that the agents reach on their trip plan contains a subsequent visiting time. This visiting time adds needed differentiation between destinations of similar settings. Layering the model in this fashion will allow the user to view specific times of the day and assess our data more critically.

3.3 FACILITATING MOBILITY WITH A SMART-PHONE APPLICATION

Our team has worked to bring the capabilities of smart-phone technology to help aid Venetian mobility in a unique way by designing a navigation aid application focused on public transit, specifically for the historic center of Venice. The application encompasses a number of useful features including a fully interactive map over which boat line data can be overlaid, a trip planner feature with a specific focus on public transit, easy access to boat schedule information, the option to set reminders to keep the individual on time towards their destination, and finally the ability to purchase and present boat tickets right from the phone.

3.3.1 INSPIRATION

As it has been discussed, Venice presents a number of unique challenges for those wishing to navigate the city. Many areas are often congested with tourists trying to find their way, which can impede the overall flow of traffic. The ACTV boat system is an excellent solution to improving mobility, but there are situations where the boat schedule operates different from the norm, which can make planning journeys difficult. It can be a stressful experience trying to find your way through the maze-like network of streets and using the public transit system, especially for those new to the city.

Even after a few short days in Venice, the team members imagined numerous tools that would be helpful features of the application. As newcomers to the island, there was a substantial period of time where we were unsure how to reach our destination, and uncertain how to best utilize the public transit system. There was certainly a learning curve before the team began to get around more efficiently. After we were accustomed to the city and knew of the best boat routes to take, a number of other features occurred to us that would appeal to those who had a base of knowledge of Venice transportation.

The team was able to approach the problem from both the perspective as newcomers, and those familiar with city during the course of this IQP. These different experiences offered the team the opportunity to view how the application would be useful to a broad spectrum of users, both to tourists and Venetians. The team was also able to speak with a number of inhabitants of Venice, and received invaluable input into how we could help individuals navigate the city.

3.3.2 CONCEPT

In our evaluation of how people use the public transit system in Venice we were able to identify how Venetians and tourists utilize the system and navigate the city in general, as well as what concerns they may have.

For tourists, their travel needs are quite straight-forward. Tourists generally have little to no knowledge of Venice transportation options, and would therefore most likely need to be guided every step of their journey if a tool were to be devised to help them. Accurate boat information is certainly useful, but for someone with no knowledge of Venice, they may not even know how to get to the boat stop, or likewise where they would need to go after getting off the boat.

Venetians however have a good base of knowledge of how to use the ACTV system. They generally know what lines they wish to take, but may not know exactly when the boat will arrive at their stop (Figure 51). Their main concerns are simply to find out when the boat will arrive, or if there are any contingencies which would affect the normal schedule.

Figure 51 - An electronic schedule board showing boat arrival times.

From our observations, it was determined that some common concerns with travelling around the city are:

1. Where am I?
2. When does the boat arrive?
3. What is the best route to take?
4. Is boat going to take me where I want to go?
5. When should I get off the boat?
6. Will I be able to catch this boat?

3.3.3 DESIGNING THE APPLICATION

With the Venice transit/navigation application proposed by this team, we wanted to address all of the needs and travel concerns that were observed, as well as provide other useful features to help individuals move around Venice more efficiently.

Through the use of smart-phone's GPS capabilities, the user will be able to quickly pinpoint exactly where they are on an interactive map of Venice, as well as browse over the map of the city. Overlaid on this map is the ability to quickly receive information on boat arrival times, as well as a trip planner feature that will recommend the best route for the user after they have input their starting and ending locations. There is also a feature to view the full boat schedule by boat stop, and also view the information by line.

The overall intent for this application is that it be relevant in a number of different situations and it appeal to a large audience. This means that it must be appealing to those who want relevant information quickly, but also to those who wish to input their data manually and focus on the finer details of their trip. The application must also be appealing to visitors of the city as well as to Venetians. Being a navigation aid, it is only logical that functionality be geared towards those on the move. For users that are on-the-go, they want to quickly be able to access exactly what data they're looking for, what time a boat arrives at a stop for example.

Besides relying on user queries, the team looked upon a number of other transit and navigation application for inspiration. The two most influential applications were Transporter[131] and iVenice.[132] Transporter, a transit application for the San Francisco Bay Area, has an excellent system of showing real time arrivals and a very simple interface. iVenice is a transit applications specifically made for Venice. It was a particularly useful source for determining exactly what features are ideal for a Venice application, as well as determining what could be improved upon. The team also drew upon Google Maps' mobile format for icons and general map layout. These examples of relevant mobile phone applications were invaluable to guiding our thoughts for how the interface of the application should appear, as well as what features we wanted to include.

3.3.4 MOCK-UP VISUAL PROTOTYPE

The first step in the development of any sort of technology is prototyping. Producing a visual-mock up of how the application will look, and the thought behind its operation and usage was the main focus for this team. The visual representation is a useful tool for publicizing the application. People are able to relate to the features and really imagine themselves interacting with the interface and using the application. The visual prototype was essential for figuring out how the application should be laid out, both for the individual screens, and the overall functionality of the application. As with any prototype, the visual mock-up is a stepping stone, a foundation for moving on towards implementation of the application.

It was determined early on that the prototype must be as realistic and thorough as possible. Realistic in the regard that the user must be able to immediately visualize that the mock up could appear on an actual smart-phone. This was achieved by using the same icons and interfaces that are used on the actual smart-phones and working to ensure that the mock up had the same "feel" as their platforms. The prototype must be thorough enough so that all it would take for implementation is a programmer to simply put the software in place to make the buttons work, all layout and operational conditions having been already covered.

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[131] Kote, Thejo, and LjubaMiljkovic.Transporter. [cited October 15 2010]. Available from http://www.transporterapp.net/index.html#features.

[132] iVenice pro. 2008 [cited October 8 2010]. Available from http://appshopper.com/travel/ivenice.

Getting to the final version of the visual prototype was a process in itself. It took a great deal of research and input from smart-phone users before a viable version was achieved. Early mock-ups of the mimicked internet browser web pages more than a smart-phone application. (See figure 52) With refinement however, it was determined the same features and overall function-ability could be achieved in a much more streamlined and application friendly format.

Figure 52 - An early visual prototype of the application done for the Android interface.

The visual prototype of the application was done in Adobe Photoshop relying primarily on downloadable Graphic User Interface (GUI) templates available online.[133] The mock up for the application was done for an iPhone interface. It was determined by the team that the iPhone is more widely recognized that other smart-phones and would therefore a wider audience would be able to relate to it.

3.3.5 CRITERIA/CONSTRAINTS

The application was designed to be able to provide the user with the most amount of information for a minimal amount of input. With the application intended to be an on-the-go tool, it is essential that the user be able to receive the information they need quickly and efficiently. This is accomplished through the use of preset defaults, storing memory of frequented settings, and automatically suggesting them. An ideal application does as much of the thinking for you as possible, enabling the user to focus on other matters rather than the particulars of their travel.

The application was designed to be easy to navigate as well. Atop every screen of the application is a menu bar that allows the user to go to the previous page, choose which function they would like to use: map, ticket, and schedule, and also have access to a settings page to adjust whatever presets they may wish to establish. (Figure 53) With this menu available at all times, it simply takes one tap for the user to jump to another feature of the application. See Appendix R.1 for more information on general navigation.

[133]Teehan, Geoff. iPhone GUI PSD version 4. 2010 [cited October 5 2010]. Available from http://www.teehanlax.com/blog/2010/06/14/iphone-gui-psd-v4/.

Figure 53 - The menu bar present on every screen.

Smart-phones are equipped with a number of useful sensors that can be applied to custom programs. With our application we plan to use many hardware features for the device: the camera, accelerometer, and GPS. The GPS will be utilized to determine the user's current location on the map, which can be applied to notify where the nearest boat stops are to them, if they will be able to catch a certain boat based on their position and the time, and of course provide the user with a reference of where they are in the city. The accelerometer can be used to determine the user's pace speed, which the application will be able to analyze and recommend they speed up should the boat be arriving soon. The camera can be used by *vaporetti* attendants to scan the ticket presented by riders.

3.3.6 GOALS

With the hopeful implementation of this application there are a number of goals we hope to accomplish through its use. The over-arching goal is to improve the mobility efficiency in Venice, which we would accomplish by building up from the simplest unit of mobility, the individual. By providing this tool to facilitate movement, we hope that we will be able to make the city of Venice easier to navigate. The team hopes to increase usage of the public transit by recommending routes and travel solutions utilizing the system. Through the use of the ticket feature, the teams hopes that they will be able to reduce costs to the ACTV by lessening the amount of hard copy tickets that will need to be printed.

4. Results and Analysis

4.1 EVALUATION OF PEDESTRIAN MOBILITY

After performing field counts of pedestrians at bridges and organizing ridership data from the ACTV, we identified a number of trends in this data.

4.1.1 TIME BRACKETS

From our full day of counts at Ponte Sant'Antonio, the following time brackets, previously described in the pedestrian methodology, were formulated:

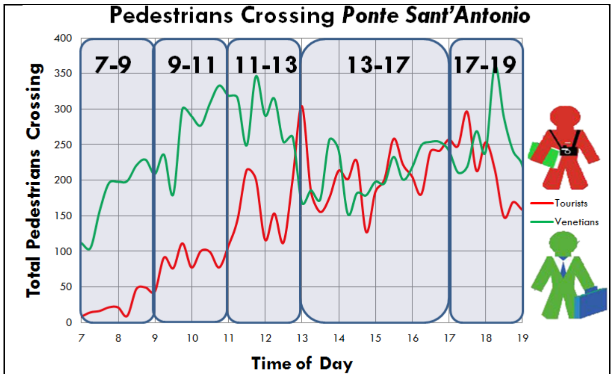

Figure 54 - Five time bracket

Table 8 - Five Time brackets

Bracket Name	Start Time	End Time
Early Morning	7:00	9:00
Morning	9:00	11:00
Mid-Day	11:00	13:00
Afternoon	13:00	17:00
Evening	17:00	19:00

During each of these time brackets, traffic was said to be reasonably homogenous with regards to total number of pedestrians crossing during the time, as well as the relative total number of tourists and Venetians crossing.

4.1.2 TOURIST AND VENETIAN PROPORTIONS AT BRIDGES

At the 10 high volume bridges for which data was collected, the following traffic levels and proportions of Venetians and tourists were observed:

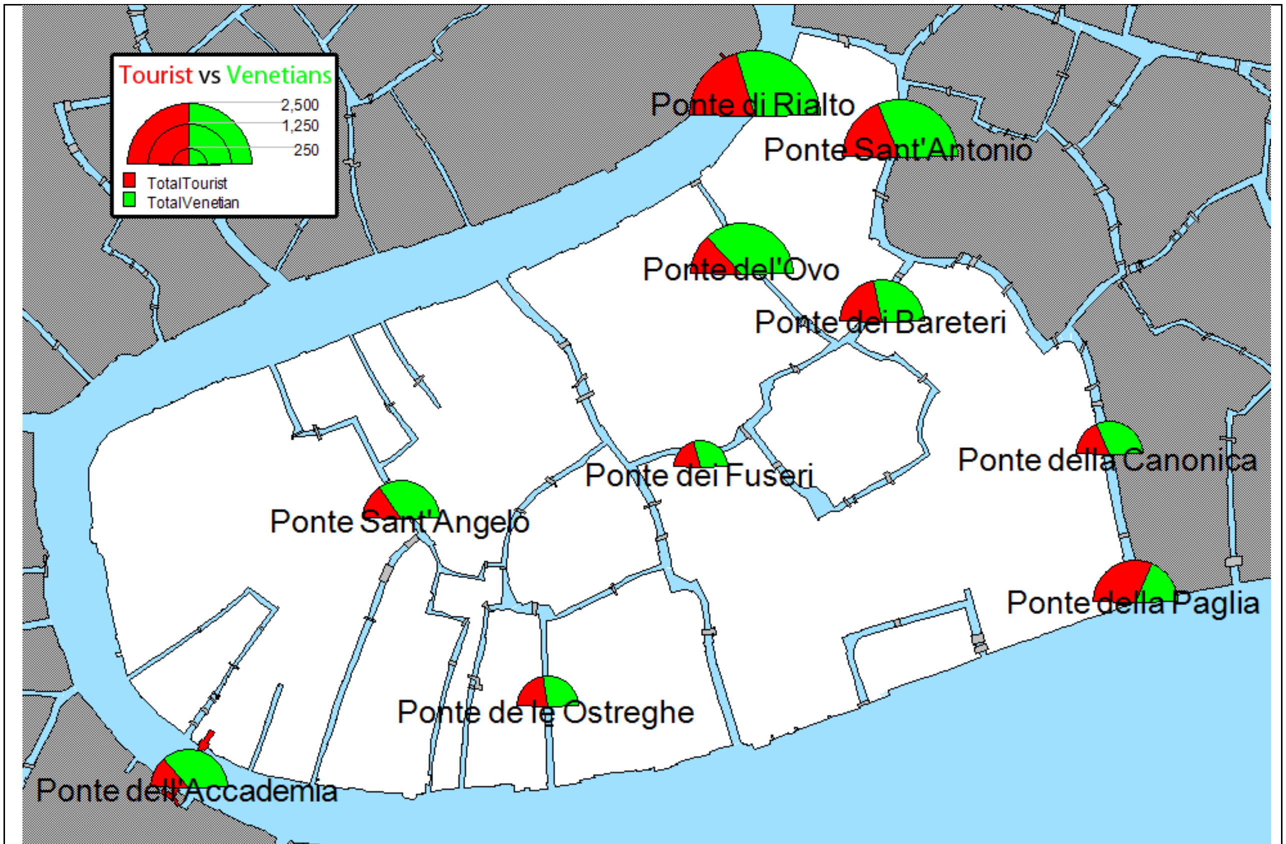

Figure 55 - Tourist and Venetian proportions at Ten bridges

Here, the size of the half-pie represents the overall volume of traffic through the bridge for the entire day. Red color represents the total number of tourists, traveling in both directions, and green represents the total number of Venetians, traveling in both directions. See Appendix J for the total counts of pedestrians crossing at these ten bridges.

As shown, the majority of these bridges in the San Marco district were used primarily by Venetians throughout the day. Only traffic over Ponte della Paglia exhibited a tourist majority. This demonstrates primarily Venetian traffic in such a highly touristed district. This can be attributed to the dates of data collection—since data was collected in early December, outside of tourist season, the population of tourists was much lower than would be expected in months during tourist seasons from April to October or November.

The following map shows traffic over bridges throughout the city as collected by a 2009 WPI team studying mobility in Venice. Similarly, totals for Venetians and tourists were represented by half-pie graphs on the map. Brides in San Marco that were counted by this 2009 team include Ponte di Rialto, Ponte dell'Accademia, Ponte della Paglia, Ponte della Canonica, Ponte de le Ostreghe, and Ponte del'Ovo.

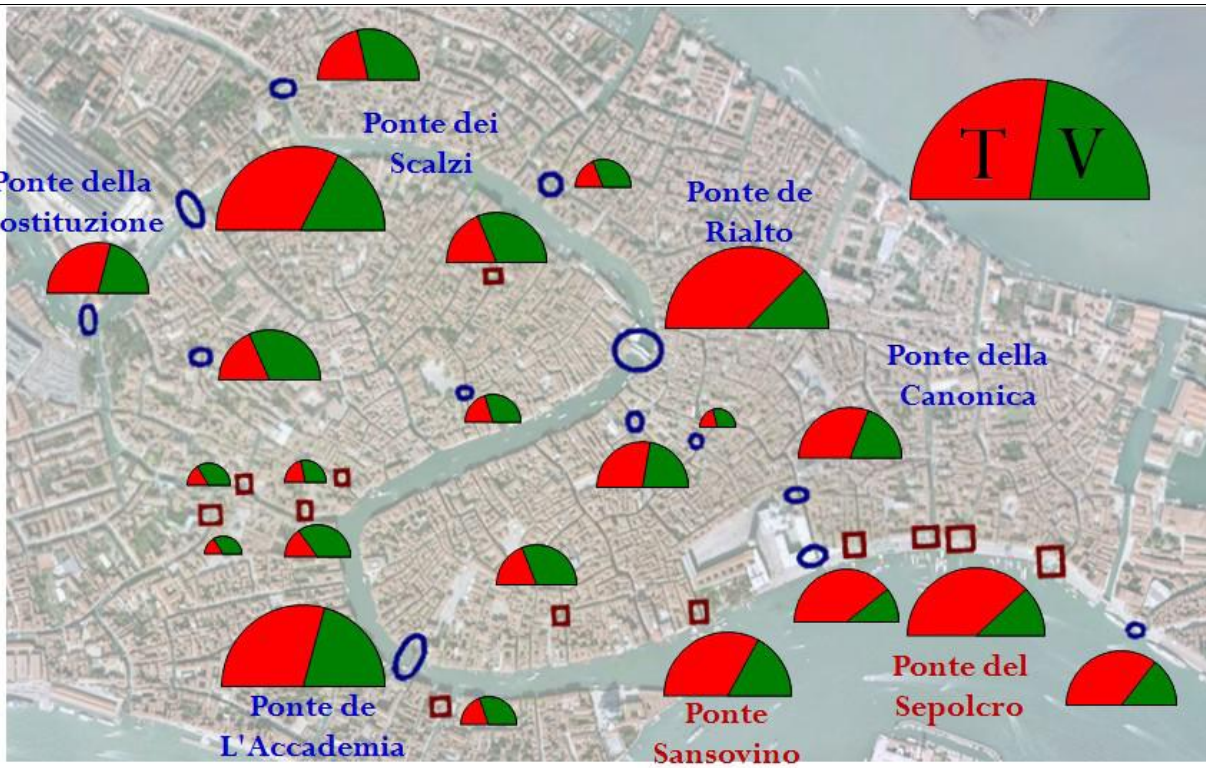

Figure 56 - 2009 Tourist and Venetian Proportions at bridges

These 2009 counts exhibit tourist majorities at all these San Marco bridges except Ponte de le Ostreghe. The primary cause contributing to the difference in proportions between these 2009 counts and this team's counts at our San Marco bridges is the different months during which data was collected. These 2009 counts were conducted primarily during November—still a touristed month in Venice. This team's 2010 counts were conducted solely during December—a colder month in Venice during which there are less tourists. This time difference, though by one month, is significant and contributes to the proportional differences of tourists at these bridges.

The relative levels of total traffic at these San Marco bridges are comparable between years, with the exception of Ponte dell'Accademia. In 2009, Ponte dell'Accademia and Ponte di Rialto both had high levels of traffic. However, this year, counts at Ponte dell'Accademia showed lower levels of traffic than at Ponte di Rialto—1062 total pedestrians at Ponte dell'Accademia as compared to 2700 pedestrians are Ponte di Rialto—although both cross the Grand Canal and are critical bridges that individuals must use to travel between the districts separated by the Grand Canal. Future studies can provide a third data set to provide insights into these differences.

4.1.3 VARIATIONS OF TRAFFIC DURING TIME BRACKETS

The following series of bar graphs displays differences in overall traffic throughout the day, for both bridges (shown in red and orange colors) and vaporetti (shown in blue and green colors). Each bar represents the total number of pedestrians crossing, in both directions, both Venetians and tourists, during the five time brackets.

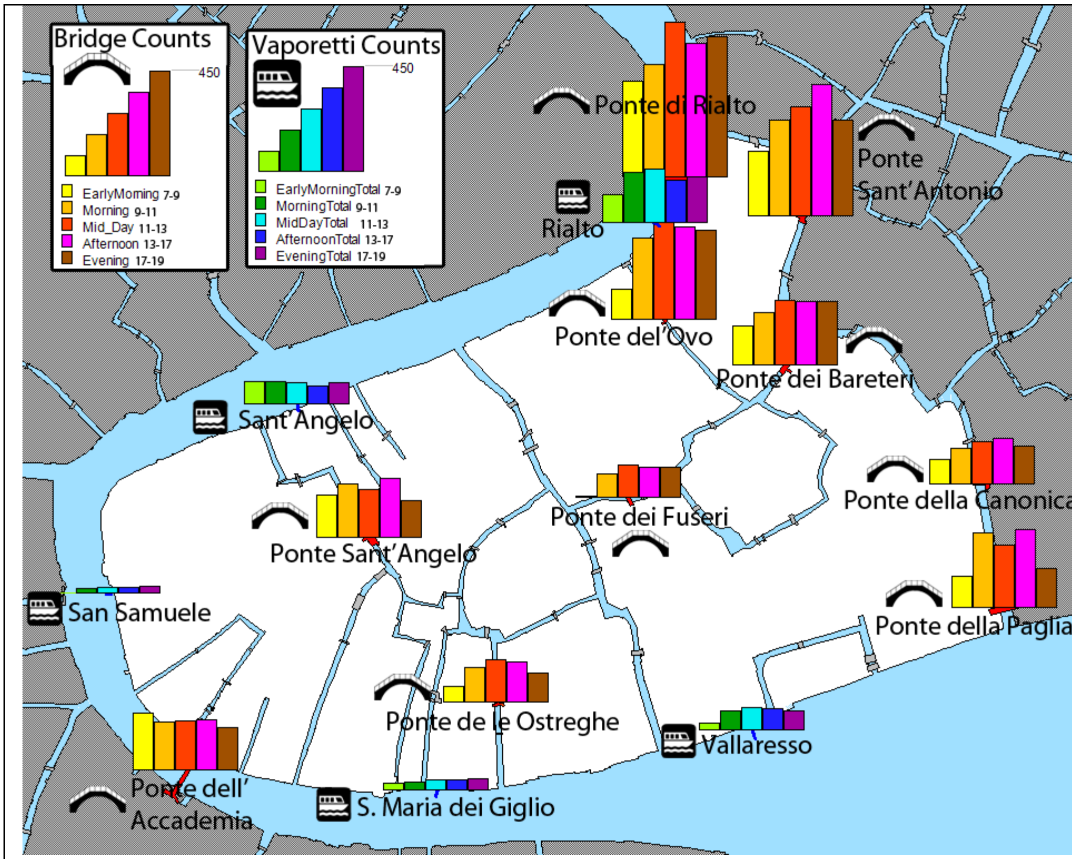

Figure 57 - Variations of total bridge and vaporetti traffic during five time brackets

The bridge used to determine these five time brackets, Ponte Sant'Antonio, shows visibly distinct totals during these brackets—which served as the basis for these specific time divisions. However, some of the other bridges did not exhibit as distinctive time brackets, such as Ponte dell'Accademia and Ponte dei Bareteri. In particular, the mid-day, afternoon, and evening time brackets exhibited similar traffic levels for a number of bridges: Ponte dell'Accademia, Ponte dei Fuseri, and Ponte dei Bareteri. The graphs shown above display the total number of pedestrians crossing—both tourists and Venetians. When divided into these two types with respect to the same five time brackets, divisions were more visible, as shown below. ACTV ridership data did not divide pedestrians into tourists or Venetians, therefore further analysis of these proportions cannot be conducted.

For these boat stops, early morning boat usage is the lowest of the five time brackets. During this time, primarily Venetians are traveling to school or work and they may be more likely to walk to their destinations than tourists traveling later in the day would be. However, in general, boat usage is relatively constant throughout the day.

4.1.4 TOURIST AND VENETIAN PROPORTIONS AT BRIDGES DURING TIME BRACKETS

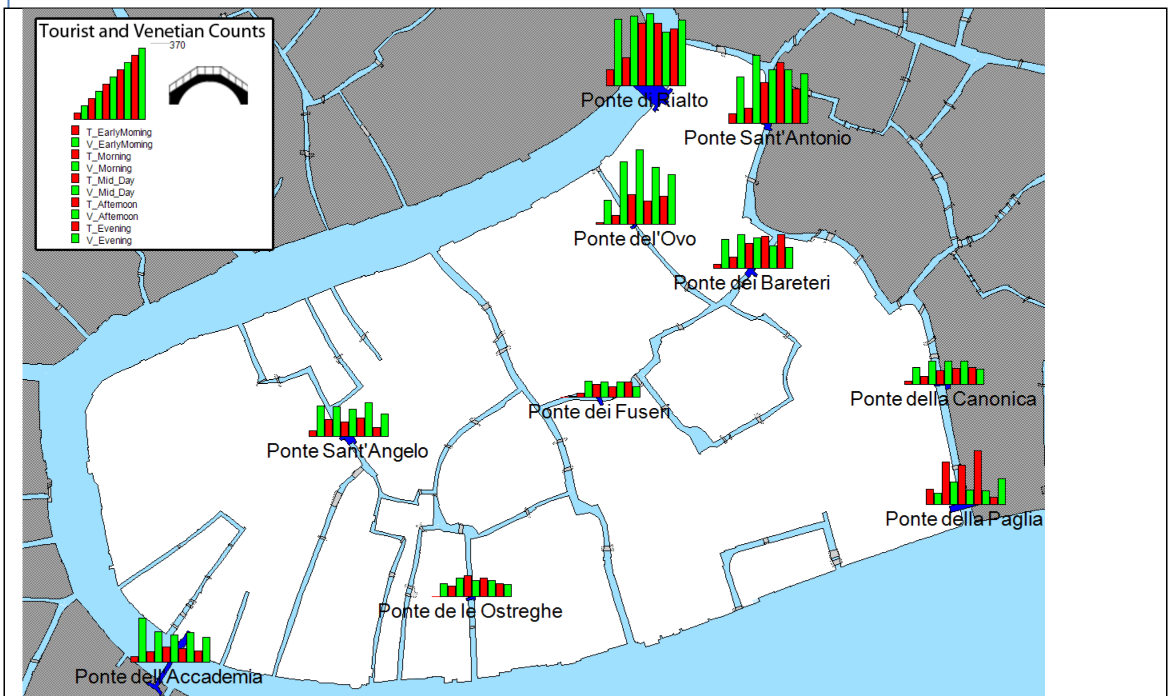

Figure 58 - Variations of Total Venetian and Tourist Traffic over Bridges During Five Time Brackets

Here, each pair of bars, red representing tourists and green for Venetians, shows the total pedestrian flows for the five time brackets in order from early morning until evening. With these divisions, Ponte dell'Accademia, Ponte dei Fuseri, and Ponte dei Bareteri demonstrate more distinct flows throughout the day. The total number of Venetians in the morning was much greater than the number of tourists; then the total number of Venetians in the afternoon/evening was much less but surpassed by the number of tourists. Therefore, the sum of total pedestrians in the morning and the sums of total pedestrians in the afternoon/evening appear to be equal in total value but are in fact distinct when considering the movements of tourists and Venetians separately. These variances in times of movement can be attributed to the fundamental movement characteristic of each of these groups—Venetians travel early to work then remain at these locations for the majority of the afternoon, while tourists travel later in the day.

4.1.5 TOTAL BRIDGE AND *VAPORETTI* TRAFFIC

All of these representations of the bridge counts and vaporetti counts show that areas near the Rialto Bridge have the highest volumes of traffic in this district—the boat stop, the Rialto Bridge, and the three bridges near Rialto (Ponte Sant'Antonio, Ponte del'Ovo, and Ponte dei Bareteri). These areas are shown circled in red on the map below.

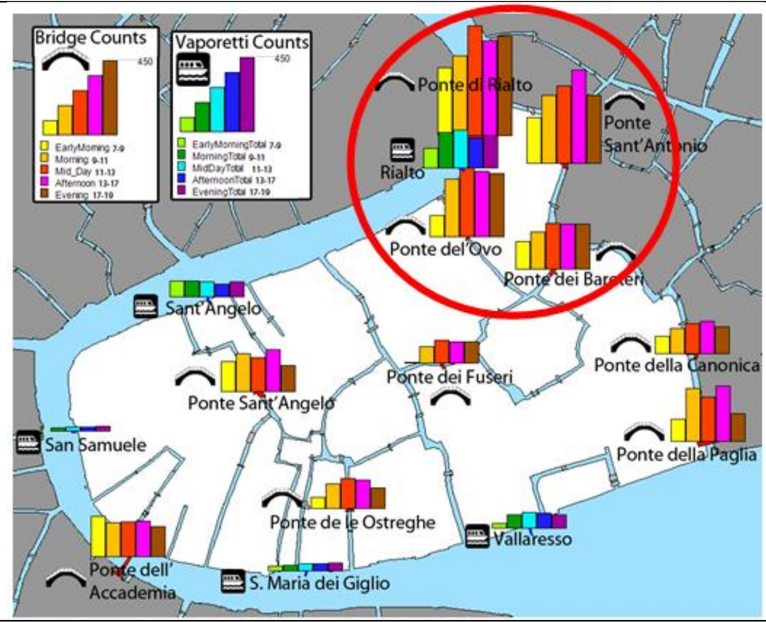

Figure 59 - Highly trafficked locations around Rialto Bridge

Since Ponte di Rialto connects San Marco to the district of San Polo and the northern and western sides of the city, we can draw the conclusion that all individuals entering the city from the *Piazzale Roma* or Ferrovia entrances are very likely to pass over the Rialto Bridge if they intend to travel to San Marco or Castello. Conversely, any tourists or residents leaving these areas to travel to these areas of the city or exit the city must travel over Rialto. Since the Rialto Bridge is a major tourist attraction, many tourists will travel over this bridge simply to take pictures or shop, contributing to the high bridge traffic in this area.

The Rialto *vaporetto* stop serves the most riders during the day, followed by Sant'Angelo and the Vallaresso boat stops. San Samuele is the least popular. The high traffic at the Rialto and Vallaresso boat stops is achieved by the total of three boat lines using these stops—lines 1, 2, and the night line. Furthermore, these two stops are adjacent to major tourist attractions: St. Mark's Square and the Rialto Bridge. It can be assumed that a great majority of the traffic at each of these locations is tourists. Also, Venetians who want to travel through San Marco or even to Castello commonly disembark at this Rialto stop and will walk to their destinations. This is often faster than continuing on a boat winding through the Grand Canal that will make many stops along route 1 down the Grand Canal, where boats must also travel slowly in this highly trafficked canal.

Sant'Angelo achieves the next highest level of traffic with only one boat line—line 1. Giglio, which similarly only serves line 1, does not receive the same levels of traffic that Sant'Angelo does, perhaps because of its proximity to the Vallaresso stop which serves all three lines. Riders traveling closer to St. Mark's Square would use the Vallaresso stop. Riders traveling closer to Accademia Bridge may instead use the Accademia boat stop, not shown on this map, but located across the canal in Dorsoduro adjacent to the Accademia Bridge. If these riders then wanted to return to the San Marco district, they could easily cross the bridge while still traveling to the Accademia boat stop rather than Giglio.

Primarily residential areas, such as around the San Samuele boat stop, exhibit lower traffic levels since these areas feature less tourist attractions and serve residents primarily. Tourist traffic contributes to the high levels of usage in other areas of the city surrounding Rialto Bridge and St. Mark's Basilica. Therefore, the lack of this tourist traffic through residential areas as shown in Figure 60 leads to the lower levels of overall traffic.

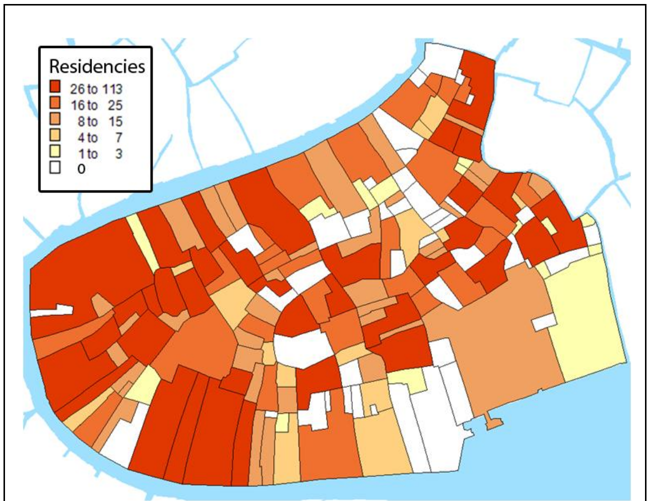

Figure 60 - Residency throughout San Marco

4.1.6 DIRECTIONS OF TRAFFIC FLOW

The five *vaporetti* stops located within this district both deliver passengers into the district as they disembark boats and remove pedestrians from the district as they board boats. Bridges transfer travelers in either direction between islands. The following map displays these directions of flows, where the size and weight of the arrow corresponds to the number of travelers. Note the different scales for *vaporetti* and bridge counts.

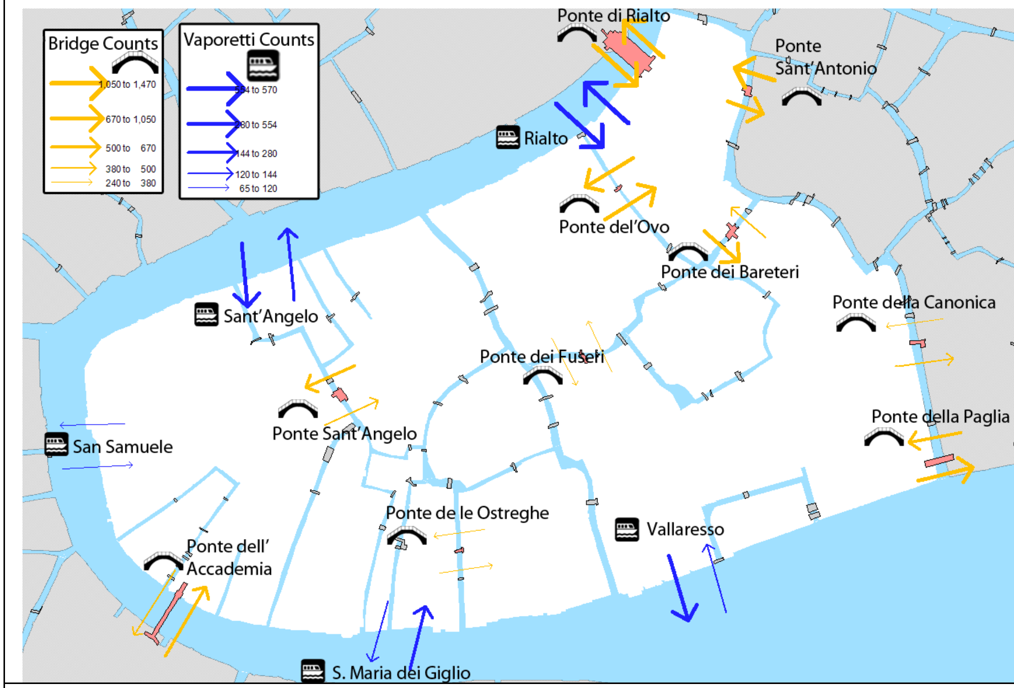

Figure 61 - Directional Flows at Bridges and Vaporetti stops

Here, the traffic over bridges surrounding the Rialto Bridge area as well as this Rialto boat stop have equal proportions of travelers in either direction. This demonstrates the overall high traffic in this area as pedestrians travel both into and out of this district in this area that provides one of the critical connections across the Grand Canal.

Over the Ponte dell'Accademia and from the Santa Maria dei Giglio boat stop, pedestrians travel into the district of San Marco more than out of the district from these areas. The number of pedestrians traveling out of the district is greater in the Vallaresso boat stop area and over Ponte della Paglia and Canonica into Castello. These three locations connect directly to St. Mark's Square. Following the theory that tourists' primary and initial destination after entering the city is St. Mark's Square, they will then travel out of this area to their next destination using one of these three exits from the island housing St. Mark's Square.

4.1.7 USE OF *TRAGHETTI*

This team performed limited counts of *traghetti* usage but due to time constraints and much less significant usage levels at *traghetti* than anticipated, this form of transportation was not studied extensively.

Due to high tide conditions during this team's field collection periods for *traghetti*, many were not operating full schedules. Later in the day, many remained closed despite lower, seemingly operable water levels. All the *traghetti* in this district are subject to high tides and are assumed to similarly close frequently due to inclement weather (rain, fog, snow) and the resultant unsafe conditions.

The following map of the heights of various walkways throughout San Marco, copies of which are located at many *vaporetti* stops, show areas susceptible to flooding. In green are areas of the district higher than 120 centimeters; a height that remains dry during the moderate high tide of 110 centimeters (the border value to be considered *acqua alta*). Orange routes are those that provide walkers with *passerelle*, the raised wooden walkways that are necessary for lower-lying areas that do flood at 110 centimeters of *acqua alta*. The five *traghetti* routes within this district are displayed with grey dashed lines.

Figure 62 - Flooding susceptibility of five traghetti locations

Out of these five *traghetti* stops, four connect to areas in orange that require *passerelle* due to their susceptibility to flooding: Riva dei Carbon, Sant'Angelo, San Samuele, and Santa Maria dei Giglio. If these areas flood regularly, *traghetti* can be expected to consequently close regularly due to unsafe operating conditions during high tides. The one stop shown to connect to an area with a height above 120 centimeters, Calle Vallaresso, was observed by this team to still close during *acqua alta*. All *traghetti* in this district are affected significantly by high tides.

Even when *traghetti* were operating, team members observed many individuals wait at the stops but go unnoticed by *traghetti* operators when the boat was situated on the opposite bank of the Grand Canal. The conclusion was made that *traghetti* do not provide a reliable or predictable enough form of transportation to be heavily used.

For the *traghetti* that were operating, the usage numbers were significantly lower than expected. This varied with location. The Riva di Carbon *traghetti* transported an average of 10 individuals and the Sant'Angelo *traghetti* an average of 15. This may be caused by their centralized location along the Grand Canal. However, *traghetti* located at the southern end of San Marco, connecting St. Mark's Square to Chiesa Santa Maria della Salute in Dorsoduro did not seem to be highly used. This may be attributed to the existence of nearby *vaporetti* stops that alternate stops on either side of the Grand Canal and allow riders to travel across the canal—thereby replacing the purpose of *traghetti*.

4.1.8 MOBILITY IMPAIRMENTS

During our full day of counts at Ponte Sant'Antonio from 6:00 until 20:00, a total of 885 mobility impairments were counted. Of these, individuals with wheeled luggage represented the majority of the mobility impairments, totally 341. The following table displays the total mobility impairments of each type counted during the entire day:

Table 9 - Mobility impairment totals

Mobility Impairment Type	Frequency During 14 Hours
Wheelchair	4
Crutches	6
Walker	1
Cane	53
Limp	6
Stroller	111
Luggage	341
Shopping Cart	194
Delivery Cart	120
Elderly	20
Large Parcels	26
Overweight/Pregnant	1
Other	2

To represent this easily, the top 5 types of mobility impairments were treated as major contributors and the remaining, less frequent 8 types were grouped into "other" in order to simplify results. See Figure 63 for a comparison of these full day totals of the top 5 mobility impairments.

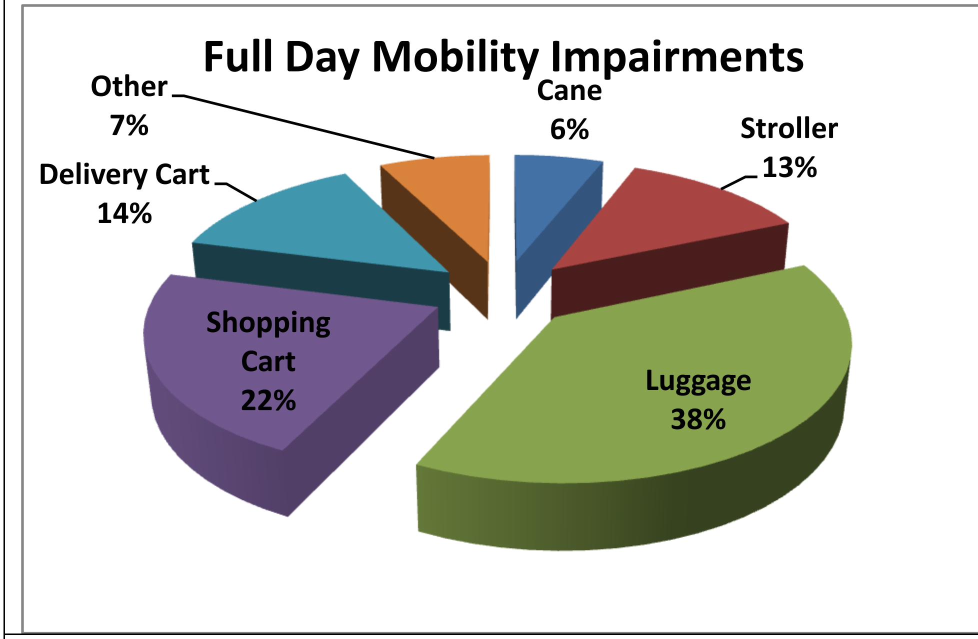

Figure 63 - Mobility impairments at Ponte Sant'Antonio

The totals for these top 5 mobility impairments averaged for the 9:00-11:00 and 16:00-18:00 time periods that the 2007 WPI team studying mobility impairments found are shown below. Also shown are the 2007 proportions for comparison. Other peak times we observed mobility impairments during were 11:00-14:00, for which nearly the same proportions were found as for the rest of the day.

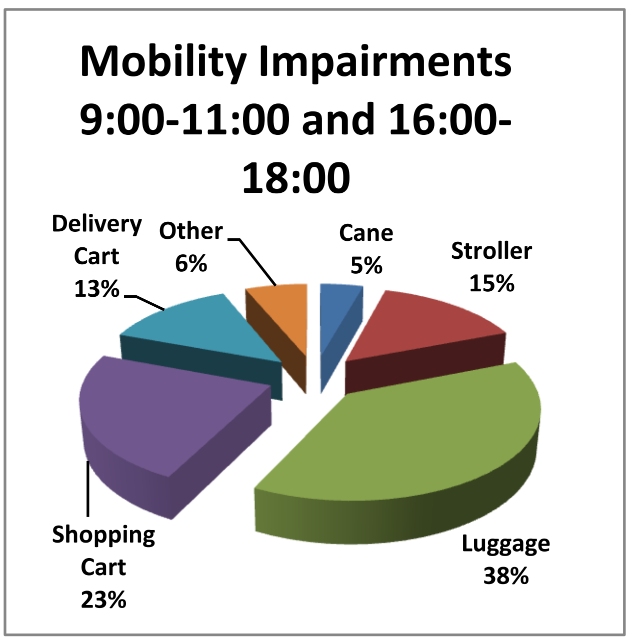

Figure 64 - Mobility impairments from 9-11 and 16-18

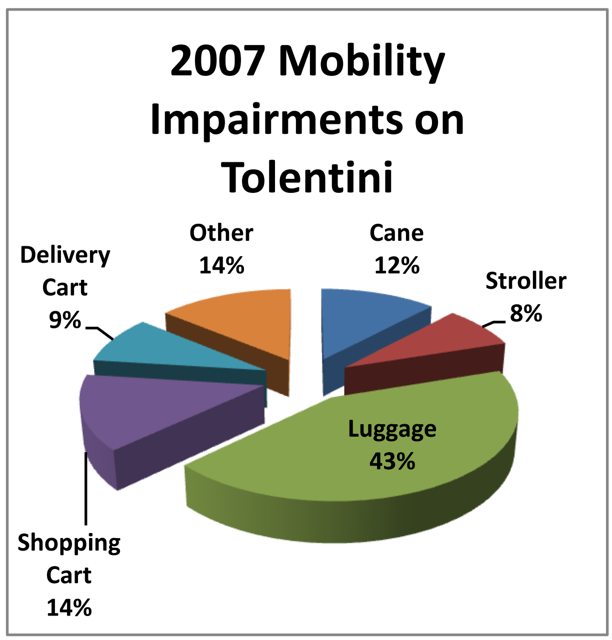

Figure 65 - Mobility impairments from 2007 studies

The relative frequencies of each type of mobility impairments are the same for all of these different divisions of the day into different peak time brackets. When compared to the 2007 study's mobility impairment data, shown below, our proportions of each type were found to closely agree despite the different locations at which data was collected.

4.1.9 EFFECTS OF *ACQUA ALTA* ON PEDESTRIAN FLOWS

For Ponte della Paglia counts during one early morning time bracket were conducted both during flooding instances and then repeated during normal tide levels. This bridge is located adjacent to St. Mark's Square, the lowest-lying area of the city highly susceptible to flooding during even slight occurrences of *acqua alta*. However, when the counts during normal tide levels and those during *acqua alta* were compared, only the following minor discrepancies were noticed which are much less drastic than predicted differences would have been for traffic flows during *acqua alta*:

Table 10 - Effects of acqua alta upon traffic at Ponte della Paglia during morning time bracket

	Normal Tide Levels	**Acqua Alta**
Venetians traveling towards St. Mark's Square	79	66
Venetians traveling away from St. Mark's Square	33	30
Tourists traveling towards St. Mark's Square	75	107
Tourists traveling away from St. Mark's Square	133	139

Here, the number of tourists traveling in both directions was surprisingly higher during acqua alta than they were during normal tide levels. During acqua alta, Ponte della Paglia can be easily accessed by the extensive *passerelle* network assembled in the flooding-prone St. Mark's Square to assist walkers without boots. This would seem to indicate no need for pedestrians' traffic routes to change. Since not all areas offer these *passarelle* for walkers, this team anticipated pedestrian routes to surely be altered during *acqua alta*, even situations when the individual must travel a route without raised walkways even in conjunction with an area that does offer the *passarelle*. However, this data indicates that tourists are likely to travel through St. Mark's Square (or over Ponte della Paglia, at least) regardless of flood levels. The flooding on this day of data collection was approximately 120 centimeters—higher levels of flooding may influence traffic differently. For this day, the extensive *passerelle* network through St. Mark's Square and along the lagoon towards Castello was sufficient enough to in fact draw more tourists to use these dry routes than other routes without *passerelle*.

Venetians traveling did not seem to be significantly affected by the *acqua alta*. These Venetians are familiar with what areas of the city are easily navigable during *acqua alta*, are prepared with reliable boots, and therefore do not need to alter their routes. During higher *acqua alta* events, these Venetians would be increasingly more likely than tourists to alter their routes since they would be familiar with routes through higher ground that are less likely to flood.

4.2 COMPUTER MODEL

The autonomous agent model provides a pathway for the heightened understanding of pedestrian mobility in Venice. This model used NetLogo v.4.1.1 as a programming language base to develop the necessary logic to simulate our designed autonomous agent model. A collaborative effort between our team and Stephen Guerin, President of the Redfish Group, developed the resulting programming code and logic (see Appendix O).

4.2.1 ENVIRONMENTAL FRAMEWORK

The final model design synthesized an authentic Venetian environment which depicts precise representations of pedestrian types. Our design uses GIS data to project an accurate map of San Marco into the model. GIS mapping technology constructed the environment of the model using accurate archived data collected throughout the years on the city of Venice. Figure 66 below shows how the GIS mapping software was used to construct the district of San Marco.

Figure 66 - GIS Map within NetLogo

The GIS data blended seamlessly into the NetLogo modeling language. The entire environment is well connected and indexed using node identification numbers. Each node identification number provides a code to the reference points that each agent can travel between. The network of nodes function as a map, thus every node knows its distance to the other nodes in the network (See Appendix N: flood-fill setup). In the walkways of the San Marco district alone there are anywhere from 700 to 800 nodes based on the model settings. The pedestrian GIS walkway layer contains enough detail to properly map all the thruways, bridges, and dead ends located in Venice. GIS map layer are updated every few years, making the modeling environment very versatile

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4.2.2 MOVEMENT OF AGENT TYPES

The agents within the model function as a visual representation of the numerous pedestrian types that move through the city center on a daily basis. The seven agent types are represented in the modeling environment, distinguishing between tourists and venetians. The trip planning process that each autonomous agent stepped through structured its behavioral characteristics. The node identification number functioned as a list of destinations that each agent could choose autonomously. A simple example of different agent situated near the many reference nodes are shown in Figure 67 below.

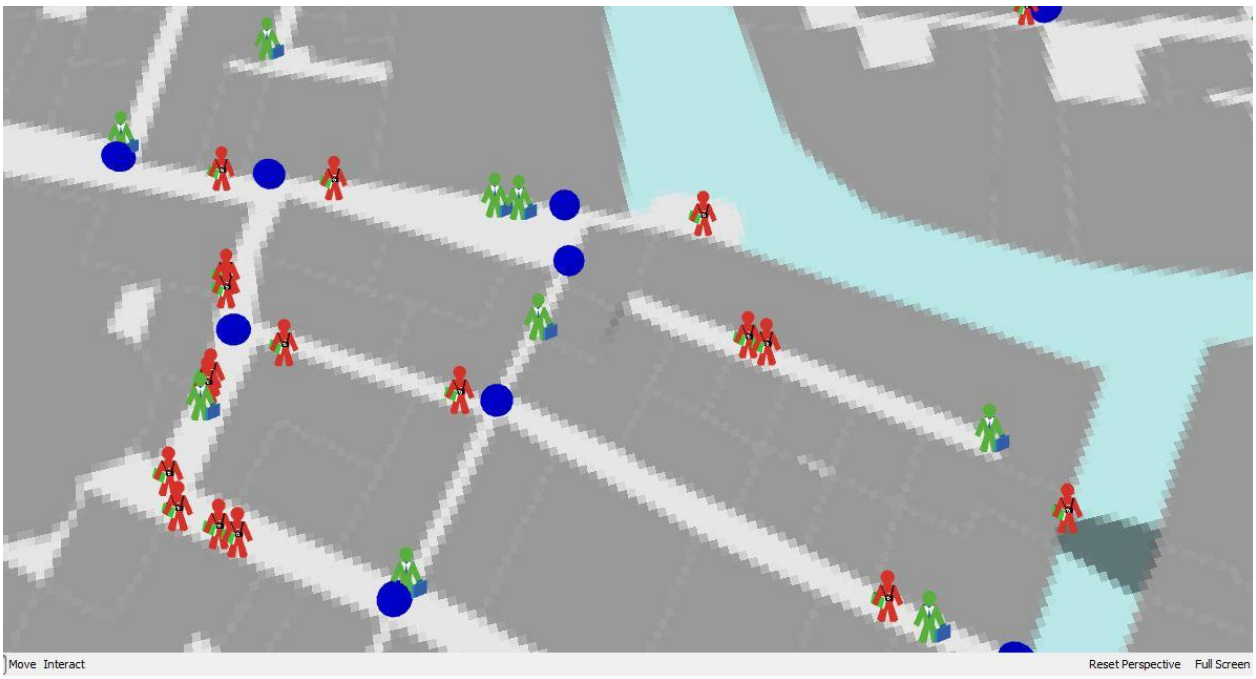

Figure 67 - Sample Screenshot of Pedestrian Agent and Reference Nodes

The Venetian and tourist agent (green and red respectively) use the reference nodes (blue) as destinations, which in turn allows the nodes to double as decision points as well. The presence of more nodes through the pedestrian walkway network in the future could provide enhanced traveling options for the agents.

4.2.3 PROOF CONCEPT

The model holistically serves as a proof of concept for a large scale autonomous agent model which encompasses the entire city of Venice. The environment of the model designed for the San Marco district, which served as an appropriate sampling district of Venice. The San Marco district has a mixture of numerous tourist locations, and Venetian residencies. The layout of bridges in relation to large traffic flow locations are another key feature of the San Marco district. Bridges such as *Ponte dei Bareteri*, and *Ponte dei Fuseri* were ideal for visually representing how people flow from the Rialto Bridge towards San Marco's Square and the Castello district. As the behaviors of the agent differentiate over time and their unique traveling patterns arise, the model will quickly reflect the changes. Autonomous agent modeling allowed our team to replicate experiments with great speed and precision. NetLogo possessed the computational power to handle 78,000 pedestrian agents scaled down to 780 actual modeling agents.

The designed pedestrian agents resembled their real world counterparts based on weights we have distributed. Each Venetian or tourist used real world destinations as points of interest for travel. For example, one day tourist could set up a one way trip. This possible trip (see Appendix P) for the day tourist would start at the Rialto Bridge and end at the Basilica di San Marco, arriving within 20-25 minutes, due to unfamiliarity. Then staying and visiting the Basilica for 30 minutes before leaving and deciding upon its next destination. In a more sophisticated model the pace of this decision making will be much higher, allowing for the model to handle vast amounts of information within the city of Venice as a whole.

4.3 FACILITATING MOBILITY WITH A SMART-PHONE APPLICATION

The application prototype was very well received by potential users when presented. They found the features highly relevant and novel, their main complaint simply being that the application isn't available for download yet. Those relatively unfamiliar with the city were, as anticipated, interested in trip planner function and the other map features, as well as the boat schedule information. Venetians were particularly receptive to the reminders. Given the positive responses of those inquired, in can be inferred that the features proposed are indeed appropriate for this application.

Figure 68 - An overview of the application features.

4.3.1 GENERAL OVERVIEW OF FEATURES

See Appendix Q for detailed visuals on the application's features.

The "Map" feature of the application will be default opening screen for when the user launches the program. The map in its most essential form will be a fully interactive map of the city, where the user will have the ability to overlay a number of layers such as the various boat lines and saved locations. The map will also be linked to the boat schedule, so the user will be able to quickly view when the next boat will be arriving right as the open the application. See Figure 69 for an example of this.

Figure 69 - An example of how the application will look as soon as the user launches the program.

Built off of the map is the "Trip Planner" feature. The trip planner will provide the user with a three recommended routes after they enter in their starting location and their desired ending location. The recommendations will be grouped as a mix of walking and taking the boat, a route which will cover the greatest amount of distance by boat, and a walking only route. After the user chooses which route they will want to take, the application will provide specific walking directions, as well as an outline of the boat trip. The user can update the route by simply tapping a refresh button.

Built into the application is the ability to purchase and show ACTV tickets right from the mobile phone. The user can specify which type of ticket they wish to purchase or link their monthly boat pass to the device. By tapping the "scan" button, the application will display a code that can be checked by the ACTV attendants in order to validate the user's boat fare. An example of what the attendant might see is shown in Figure 70.

Figure 70 - An example of what the *vaporetto* attendant might see after scanning a ticket on the application.

The “Schedule” feature will allow the user access to the full boat schedule organized by boat stop. The user can view when the individual boats leave from that stop, as well as scroll the time forward to see when future boats are leaving.

The option of setting reminders is one feature that makes our application stand out from other navigation and transit applications. The user will be able to set a reminder of when it is necessary for them to begin a journey in order to make the boat on time. Going along with this departure reminder, the application can prompt the user if they need to increase their walking speed should they be in danger of missing their boat. And finally, the user can be prompted while they are riding the boat to disembark when their desired stop is coming up.

4.3.2 EXAMPLES OF USE

To best view how the application will be used we will evaluate two specific examples: one of a tourist, and one for a Venetian.

Let’s imagine a tourist arrives in *Piazzale Roma*. They have no knowledge of how to get around Venice and their mobility is limited by the luggage they have with them. The user launches the application and chooses the trip planner function (see Appendix Q.3). The application has by default set the starting location as their GPS position, and the time settings to arrive at the Destination as soon as possible. The only required input is to choose the ending location, which the user does by typing in the address of their hotel. They save the hotel address as a favorite so they may quickly choose this again at a later date.

With all the required information provided, the application returns three possible routes for the user: a walking only route, a mixed route of walking and using the boat which recommends taking Line 2 down the Grand Canal, and a route utilizing the most use of boat transportation which will take the user on Line 42 around the perimeter of the island. The user has luggage with them, and therefore choose the “most boat” route because it will require the least amount of walking. After choosing this option, the application provides detailed walking directions and information on the boat line they will be utilizing.

After the user has been guided to the boat stop, they purchase a single fare ticket through the application and board the boat. In route, they are prompted by the device that their stop is next and disembark. They open the application again once on land and use the walking directions to get to their hotel.

Venetians will most likely choose to use the application to view contingencies and particularities of the boat schedule. One instance where this would be helpful is late at night when the boat schedule is abbreviated. Let’s consider a Venetian out at night with friends. They want to know when the boat will de departing from the nearest stop, but do not want to waste time at the boat stop waiting when they could be spending that time with their company. They also want to make sure that they do not miss the boat, because it will most likely be a substantial amount of time before the next boat comes.

To address these concerns, the user opens up the schedule feature in the application. (See Appendix Q.5) It shows information for the stop the user is closest to by default and displays when the next boats will arrive. The user wants to plan out what boat they will take later in the night so they scroll the time forward to

1am, which is when the user thinks they will be ready to leave. They see that Line N is the only line operating at that time from that stop, and set a reminder for the boat closest to 1am.

Later in the night, the phone buzzes and notifies the user that they should leave within the next few minutes if they are to make the boat they specified. The user leaves for the boat strolling at a leisurely pace. On the way to the boat stop the phone buzzes again and recommends that the user speed up to ensure they make the boat on time. Knowing it will be quite a while before the next boat comes should they miss the boat they are in route towards, the user pays heed and picks up the pace. They catch the boat right on time and are on their way home.

5. Recommendations

5.1 PEDESTRIAN MOBILITY EVALUATION RECOMMENDATIONS

To increase the scope and usefulness of the computer model and gain a more thorough understanding of pedestrian mobility, more extensive pedestrian counts can be performed and used to support the model. Future studies can supplement the data collected for the district of San Marco as well as the other five districts of the city, the entrances to the city, and unique circumstances affecting mobility.

5.1.1 EXTENSION OF BRIDGE COUNTING METHODOLOGY

Future studies can supplement the data collected for the district of San Marco at its remaining 60 bridges. Though not all 60 bridges must be studied, more high volume bridges should be identified and studied to determine tourist and Venetian proportions at different bridges close to one another. This would provide insight as to the specific bridge choices each class is likely to choose when faced with a number of bridges located close to one another that connect the same islands, such as Ponte de la Guerra, Ponte de Ca'Balbi, and Ponte de la Malvasia, shown in Figure 71.

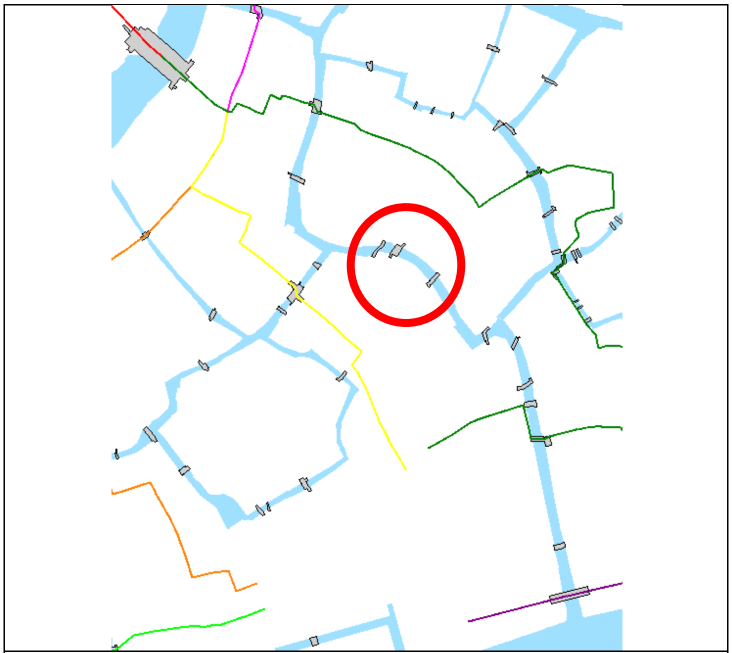

Figure 71 - Three similar bridges connecting the same islands

Repeated counts at some of the high volume bridges this year would allow for further comparison with tourist-Venetian proportions collected in 2009. Repeated counts of Ponte di Rialto and Ponte dell'Accademia in particular would clarify discrepancies among 2009 and 2010 counts.

Other districts of the city can be studied to determine flows throughout the city as a whole. Criteria for identifying critical and representative bridges at which to count will vary among districts, since primarily residential areas with few tourist attractions, such as Castello, will not have highly touristed routes to signify high traffic areas. In these cases, routes leading to areas with large numbers of jobs should be identified and used to determine highly traffic routes.

Studies of the entire city's mobility must include daily commuter and tourist influxes. These large numbers of pedestrians entering the city often within the morning same time period impact mobility significantly and create a ripple effect of traffic throughout the city.

5.1.2 PONTE DI RIALTO COUNTING

In order to count the three lanes of traffic simultaneously, a total of six counters are needed if each is to focus on traffic in one direction. The traffic along the two exterior lanes of travel varies significantly in overall totals and in tourist-Venetian proportions and therefore requires simultaneous counts for accurate comparison.

Since Ponte di Rialto functions as both a major tourist attraction and a major bridge crossing the Grand Canal, it should be treated as serving each of these purposes separately. During field counts, this team observed a large number of individuals climbing to the top of the bridge to take pictures then returning to the side of the bridge they originated from. A large number of individuals also spent time shopping at the many stories lining the interior lane of traffic. These groups of people who do not use the bridge primarily as a link between the two sides of the Grand Canal exhibit significantly different behavior than those who travel swiftly across the bridge.

To account for these differences, team members should count separately the number of individuals who travel across the bridge, the number of individuals who linger on the bridge for an extended period of time (the length of which should be determined), and the number of individuals who change directions mid-way over the bridge.

5.1.3 TEMPORAL DIFFERENCES

Data collected by this team represents traffic in the month of December, and data collected by the 2009 team represents November. Since neither of these can provide accurate extrapolations for traffic during peak tourist months or festivals such as Carnivale, future researches should vary the collection periods to include a wider temporal range. Since WPI projects are conducted during a seven-week term from late October until mid-December, WPI students can continue studies of traffic during these months to understand the decreasing tourist populations within the city during this exit from tourist season.

5.1.4 INTERSECTIONS OF BOAT AND PEDESTRIAN TRAFFIC

Since boats can discharge (or remove) large numbers of people to/from an area at one time, further studies of traffic at boat stops should be conducted. Dispersion from these unions of boat and pedestrian traffic can provide insight as to how the classes of pedestrians use these boat stops. This will help validate assumptions such as that Venetians use the Rialto *vaporetto* stop not as their final destinations but as a mid-way point to help them avoid lengthy boat rides winding through the Grand Canal.

5.1.4.1 *VAPORETTI*

The proportions of tourists and Venetians at boat stops would provide insights to the transportation choices made by each class. Since this data was collected at bridge locations, this data should be determined at *vaporetti* stops by counting tourist and Venetian boarding and disembarking during the five time brackets. This would also allow for comparison of the ACTV ridership totals between years, since the available data was collected prior to 2009, when it was received by WPI. More recent ridership data from the ACTV should be solicited to provide comparison between years.

5.1.4.2 *TRAGHETTI*

Studies of *traghetti* should be conducted when possible to complete studies of all three types of transportation between islands. *Traghetti* rowers may be interviewed to gain more substantial information regarding peak times of *traghetti* use (times of day, week, or seasons) and primary groups who utilize this type of transportation.

5.1.5 MOBILITY IMPAIRMENTS

Determining the proportion of Venetians and tourists with mobility impairments (and also within age brackets) would allow for a more accurate computer model. Counts of mobility impairments and the individual's tourist-Venetian distinction should be conducted again Ponte Sant'Antonio. The age bracket for Venetians should be recorded as well.

5.1.6 NEW SITUATIONS TO STUDY

Unique circumstances affecting mobility impairments should be studied. Mobility during *acqua alta*, a frequent occurrence in the late Autumn months in Venice but also common throughout the year, should be observed and visualized.

Other types of weather conditions expected to affect mobility include heavy rain, extreme cold, snow, and frequent fog. Studying each of these conditions and the range of resultant mobility impediments is important to gain a complete view into Venetian mobility.

5.1.7 INTERESTING STATISTICS/LOCATIONS TO OBTAIN

Helpful information to be obtained, either by performing counts or by soliciting this information from reliable sources, includes:

- The correlation between work and home locations. Though incorporation of exact data detailing specific individuals' home and work locations in any computer model would void agents' autonomous nature, some information regarding these locations would increase the model's accuracy while maintaining its autonomy. The number of residents of San Marco (or other districts once data has been collected and organized for these areas) who actually work in this district would be a useful proportion to incorporate into the model. The number of residents who travel to other districts and who leave the city would help visualize the correct directions of movement to these destinations.
- More precise locations of schools within the district of San Marco, and exact school schedules for Venetian youths. This would increase the realism of this agent type's movement.
- Locations of supermarkets, grocery stores, and small, traditional, specialty food stores (called *alimentari),* to help visualize Venetians' routes. Since many Venetians shop for food daily and will stop at these locations on their normal routes home from work, their routes will generally be altered minimally but still significantly.
- The times individuals truly spend at each tourist attraction. Based on a general sense of tourist attractions' size, priority, and type of attraction as well as personal experience, the team estimated lengths of time tourists will spend at a variety of specific attractions within San Marco. Interviews of

individuals who work at some tourist attractions or some tourists exiting attractions asking the time spent inside would provide insight into this. Counts of specific individuals entering and exiting locations would be infeasible since identifying specific individuals would prove difficult, and waiting some length of time for these individuals to exit would be impractical.

- A more sophisticated ranking system of the popularity of various tourist attractions. A sample of this system could be created using basic knowledge of the city's tourist attractions. This could be supplemented with statistics of museum attendance from the City of Venice's office of Image, Marketing, Service, and Communications. Church attendance should be researched and solicited from the Venice Church Association, Chorus. Organizations that may have attendance data for other tourist attractions should be identified and data obtained from, if possible. A number of highly important locations, such as St. Mark's Basilica, the Doge's Palace, Scuole Grande di San Rocco should have their priority ranked accurately since these are highly touristed areas.
- The number of university students living in the city and their respective universities.

5.2 COMPUTER MODEL RECOMMENDATIONS

The model created by this team serves as proof-of-concept for the incorporation of various agent types, actual field counts, and locations of realistic destination. Due to the limited capabilities of the modeling platform used for this project, NetLogo, it cannot be expanded sufficiently enough over time to incorporate great increases in focus area and data. More sophisticated computer modeling platforms that can adequately handle the data demands and complexity of this project should be researched. A student with a background in computer model programming and experience modeling would help bring success to this project in the future.

5.2.1 REFINEMENT OF PROPORTIONS APPLIED IN CURRENT MODEL

- Randomize the time people leave their origins in the morning. Normal curve.
- Mobility impairments more evenly distributed
- Break down children into further groups: elementary school, middle school, high school; then also find out about college students commute in

5.2.2 COMPLETE MODEL OF MOBILITY IN VENICE

Since a model of boat traffic in Venice has already been created, future work can create an inclusive model that combines both the boat and pedestrian models. This model would then simulate all traffic within the city of Venice and demonstrate users' combined use of both means of transportation.

5.3 SMART-PHONE NAVIGATION APPLICATION RECOMMENDATIONS

With a detailed visual mock-up of the smart-phone application created, the next step in the process is implementation. Programming an application can prove to be an extremely expensive endeavor, which will prove to be a major obstacle for the realization of a full working finished product. That aside, there are also many more opportunities for expansion in the field of mobility applications in Venice. Two main features this team evaluated briefly are a boat request system for nocturnal lines and a traffic advisor the help steer the user away from areas of high congestion.

The best chance for the successful implementation of the application lies with the ACTV. The organization can benefit a great deal from the application, has direct access to the transit schedules and lines, and will most likely have the appropriate funds to finance its development. The application has been tailored around the Venetian boat lines, and the overall goals of the applications design are to promote use of the system and reduce costs to the transit authority, making the ACTV a logical potential financier. The ACTV has direct access to the boat schedule information due to the fact they are quite simply the source of it. If the application were managed by the ACTV, they would be able to update the schedule of any changes with ease, ensuring that there would be as few errors as possible with the schedule feature. Most importantly, being a relatively large organization with government ties, the ACTV would be the most likely to have the necessary funds to appropriate to the application development. Direct contact with the ACTV and well thought out business plan would be essential to making a partnership with the organization to develop the application a reality.

Should the ACTV prove not to be interested, an outside entity may be utilized to produce the final version of the application. As it has been mentioned, the application proposed by this team has the ability to manage purchases of tickets. If an external financier or developer proposes to make the application, there may be the possibility to make an agreement with the ACTV in terms of ticket pricing. If the ACTV is willing to allow the developer to keep a portion of every ticket sold as a commission, there may be the possibility for the developing organization to receive a return on its investment, and possibly turn this into a profitable business venture

The application this team has proposed entails features that were determined to be ideal for navigating the city of Venice. There are certainly some features that can be omitted or changed to fit a more realistic development budget. A simplified application will be easier and less expensive to program, which may attract more potential developers.

Assuming the application can be implemented there is also the marketing issue to consider. Through the informal research this team has conducted, there seems to be a powerful desire for an application with the features we've provided. While to product may have appeal, it could prove a bust should there be no widespread knowledge of its existence. The application is relevant only to the city of Venice, with the target audience being native Venetians and visitors to the city. To spread knowledge of the application amongst native inhabitants, a viral campaign could be launched offering discounts on boat tickets. To appeal to tourists, advertisements could be posted on tourism advisor websites and at *vaporetto* stops.

In addition to actual implementation of the application, there are other features that can be explored as potential new applications, or additions to the one proposed in this report. Two options explored by this team are a traffic advisor and boat request system.

The traffic advisor was imagined to be a notification system that would alert the user if a route proposed by the application would be taking them through an area of high congestion. This notification could be dismissed, or acknowledged and therefore a new route around this area of congestion could be recommended. This would ideally rely on pedestrian data collected by other sources and also take into account season, time of day, and location.

A nocturnal boat request system was explored by this team as well. As it has been discussed, the ACTV operates abbreviated schedules and lines in the night hours, especially in outer areas of the lagoon. With the request system, the user would ideally be able to notify an external server of their desire to get picked up at a certain stop, and a *vaporetto* would pick them up on their next pass. A number of different aspects will need to be considered to make this feature a reality. A computer server to receive the requests and dispatch the *vaporetto* will need to be established in terms of infrastructural requirements. Most importantly, a streamline operational plan will need to be determined to ensure that this system is cost effective for the ACTV, and useful for its users. There are a number of problems that arise with this potential system, such as how many requests will need to be received in order to warrant a boat trip? Or how much would the ACTV be able to save in operational costs should they engage in this sort of "on demand" night system? A detailed cost-benefit analysis must be drafted to determine if this is a viable feature taking into account the user, and the ACTV.

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Appendices

APPENDIX A – ANNOTATED BIBLIOGRAPHY

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Information from the Venetian Government site about accessibility around the city. Excellent maps and information about what areas of the city are handicapped accessible. Will be extremely useful when considering the mobility impaired agent aspect of the model.

Aloisio, Christopher, Jason Gabriel, Kara Greenfield, and Alexander Kelly. 2009. *Venetian mobility on land and sea.* (accessed 2010).

This 2009 Interdisciplinary Qualifying Project project analyzed pedestrian movement in the city of Venice, Italy through counting and observing Venetians and tourists at key bridges and boat stops throughout the city. Data was collected at these locations, as well as retrieved from the ACTV and the Venetian Census Bureau. An autonomous-agent computer model was developed to simulate and visualize pedestrian movement based on the collected data, with the overall goal of assisting city officials with municipal planning upon its utilization.

Black, Kevin, Sara Migdal, Michael Morin, Dukens Rene, and Nick Vitello. 2007. *Urban maintenance: Assessing venetian quality of life.* Worcester Polytechnic Institute

This 2007 Interdisciplinary Qualifying Project completed by WPI students quantified mobility impairments in 12 categories, primarily on the island of Tolentini near the Ponte della Liberta entrance to Venice. They identified two peak time brackets during which they recorded the most mobility impairments. When we performed our field counts, counting all of these types of mobility impairments was infeasible. We performed a full day of counts and compared our data to their proportions to determine if there was any chance from 2007 to 2010 and if Tolentini's proximity to the entrance to the city would yield a higher rate of luggage than would be characteristic for our study area of San Marco.

Brown, Ahmend S, D., DeCourcey, C., & Keeley, J. TripBuddy: Mobile trip assistant.

The design of this application was developed at Bentley University. TripBuddy is a travel assistance tool for mobile phones that encourages green transportation by offering trip planning and navigation capabilities for public transit, walking and biking. It leverages the familiar interfaces and conventions of such well-known applications as Google Maps, MBTA trip planner and TomTom. The groups of people that travel by foot in Venice need a better mapped system for traveling.

Bruttomesso, R., & Moretti, M. (Eds.). (1995. Cities on Water and Transport International Centre Cities on Water, 1995.

This collection of articles about a number of cities that utilize water transportation focuses a large section on Venice, Italy (about 7-10 articles). These articles have been written by professors of

architectural and technical institutes, members of the port authority, the director of the ACTV, and other technical individuals in Italy. Most of these of the articles provide project proposals to increase the functionality of the lagoon, develop the urban public transport system, and discussion of environmental impacts of this boat traffic. These articles promise to be very insightful as to the work Italian authorities are considering performing and what practical solutions they have reviewed.

Carrera, Fabio, A. Gallo and A. Novello. (2006). "Street Performances: the role of visual analysis in the micro-zoning of public space in Venice, Italy". Workshop in Visual Analytics & Spatial Decision Support for the 2006 GIScience Conference, Muenster, Germany, Sept. 20-23, 2006.

This is Prof. Carrera's paper on the plateatici. It offers insight into how to approach this problem and suggestions into how to improve the system. It will provide a useful background and discussion of solutions undergoing discussion.

Catanese, Christopher D., Danice Yequay Chou, Bethany J. Lagrant, and Rudy E. Pinkham. 2008. *Floating around venice: Developing mobility management tool.* 121208-061724 (accessed September 17, 2010).

This 2008 Interdisciplinary Qualifying Project monitored boat traffic at 19 canal intersection locations in Venice to improve the accuracy of a boat traffic model being developed by the Redfish Group. The completed model can be used to simulate the impact of changes in boat traffic regulations. Also, a pedestrian monitoring methodology was developed to characterize behaviors of pedestrians in Venice. This model can be used to manage *plateatici* (public spaces rented to private entities), which frequently infringe on pedestrian walkways.

Degtyarev, A. B., & Logvinenko, Y. V. (2010). Agent system service for supporting river boats navigation. Procedia Computer Science, 1(1), 2711-2716. doi:DOI: 10.1016/j.procs.2010.04.30

This study was conducted at St.Petersburg State University in Russia. The agent system service developed by these researchers' aides in solving the troubles of river boats navigation and creating the cheapest and efficient solution for boats without onboard radiolocation system. They accomplished this by heavily noting rivers and their respective harborage networks. Venice known for its necessary shipping routes, but what is unknown is how effective they really are.

Fajardo, J. T. B., & Oppus, C. M. (2010). Implementation of an android-based disaster management system. Paper presented at the Proceedings of the 9th WSEAS International Conference on Electronics, Hardware, Wireless and Optical Communications, 126-130.

The authors of this article completed their study at Ateneo de Manila University located in the Phillipines. The disaster management system Android application known as MyDisasterDroid determines the optimum route along different geographical locations that the volunteers and rescuers need to take in order to serve the most number of people and provide maximum coverage of the area in the shortest possible time. Knowing Venice's history of flooding a similar application can benefit the response teams of the city.

Gonçalves, Luiz, Marcelo Kallmann, and Daniel Thalmann. "Defining Behaviors for Autonomous Agents Based on Local Perception and Smart Objects." Computers & Graphics 26.6 (2002): 887-97. Web.

This resource is about providing autonomous agents with local perception. They use a control theory approach which allows the agents to react to their environment independent of user interaction, learning the characteristics of their habitat and adapting to it in order to survive.

Imboden, Cheryl, and Durant Imboden. Venice for Visitors: Accessible Venice. 14 Sep. 2008. 14 Sep. 2010 <http://europeforvisitors.com/venice/articles/accessible_venice.htm>.

This site is a great resource for first hand advice for mobility impaired people. It outlines how a disabled person would be able to navigate around Venice. This will be useful when describing how the model can be used to aid people with mobility impairments, and can also give us insight into how to form our model around this constraint. The site also has a number of links for other quick facts on how mobility impairments are addressed in Venice.

iVenice pro. 2008 [cited October 8 2010]. Available from http://appshopper.com/travel/ivenice.

iVenice is a transit application made specifically for the ACTV system in Venice. iVenice was an important resource for this team when determining how best to display and organize the boat information. iVenice was a useful tool for determining what features would be useful for the application designed by this team, as well as what could be improved upon.

Izquierdo, J., et al. "Forecasting Pedestrian Evacuation Times by using Swarm Intelligence." Physica A: Statistical Mechanics and its Applications 388.7 (2009): 1213-20. Web.

This paper describes a model for an evacuation simulation and estimating evacuation times. The multi-agent-based simulation characteristics of Particle Swarm Optimization (PSO) combine individual and collective intelligence making it suitable for simulating evacuation situations. The PSO-based model assesses the behavioral patterns followed by individuals during an evacuation, and evaluation of these behaviors can address a range of public safety issues, such as architectural design and regulation of public space.

Kote, Thejo, and Ljuba Miljkovic. Transporter. [cited October 15 2010]. Available from http://www.transporterapp.net/index.html#features.

Transporter is an award winning transit application for public transportation in the San Francisco Bay Area. Transporter was designed for users that already had a base of knowledge of public transportation in San Francisco, and was useful for determining which features would be appealing to native Venetians. Transporter was also an important source of inspiration for the layout and organization of the application designed by this team.

Kutz, M. (2003). Handbook of transportation engineering McGraw-Hill.

This university level textbook provides the basics of traffic engineering modeling. There is a section entitled "Non-Automobile Transportation" that discusses pedestrian's needs and role in traffic planning which will be helpful for the pedestrian modeling in Venice. There is no section designated

for boat traffic except maritime transportation, so this textbook will primarily be used to gain an understanding of traffic modeling methods and pedestrian considerations.

Lund, Jenny, Joshua Luther, Tobin McGee, and Stephanie Miskell. 2008. *Life in the "city of water".*Worcester Polytechnic Institute.

This 2008 Interdisciplinary Qualifying Project completed by WPI students studied the quality of live in Venice through interviews and surveys of residents and former residents. This provided insight into the aspects of Venice that these individuals dislike, such as the high cost of living and more relevant for this paper, the high levels of tourism and the corresponding congestion and difficulty moving around the city. They also conducted research into the exact housing cost change.

Panahi, S., and M. R. Delavar. "A GIS-based Dynamic Shortest Path Determination in Emergency Vehicles." World Applied Sciences Journal 3.1 (2008): 88-94. Print.

This resource outlines the theory and method of using the shortest route algorithm while overlaid on a GIS model. This will be extremely useful when addressing the emergency response facet of the model.

Scaramuzzi, Isabella, Giuseppina Di Monte, Cristiana Pedenzini, and Giovanni Santoro. 2009. *Turismo sostenibile a venezia.* Venice: COSES, 141.

This report was published by the research study organization in Venice, COSES. This particular report discussed the sustainability and carrying capacity of Venice and provided some estimates for the vaporetti and other means of public transportation, as well as an estimate for St. Mark's Square: 134,000 individuals. The report also provides estimates of the numbers of people entering the city every day by various means, helpful for determining locations that tourists enter the city and cause congestion in. This report is in Italian so tables were used heavily and limited portions translated.

Teehan, Geoff. iPhone GUI PSD version 4. 2010 [cited October 5 2010]. Available from http://www.teehanlax.com/blog/2010/06/14/iphone-gui-psd-v4/.

This resource displays a Graphic User Interface Adobe Photoshop Template for the iPhone. The team was able to design a display for the mock-up prototype that very closely mimics the actual iPhone interface by copying and pasting designs from this template.

Usher, John M., and Lesley Strawderman. "Simulating Operational Behaviors of Pedestrian Navigation." Computers & Industrial Engineering (2010) In Press, Corrected ProofWeb.

This article describes the development of ISAPT (Intermodal Simulator for the Analysis of Pedestrian Traffic). ISAPT was created from the observed behaviors of pedestrians and simulates similar tactics employed by them for collision avoidance such as changes in speed and trajectory and passing strategies. The autonomous agent models follow the experimental knowledge gained from observing pedestrians' interactions within intermodal.

***The Venice Report: Demography, tourism, financing and change of use of buildings.* 2009. Cambridge University Press.**

This report was collaboratively produced by a number of groups and non-profit organizations to raise awareness about Venice's changing demographics, economy, increasing tourism, and catering to this tourism. Groups involved include the Venice in Peril Fund, Universitá IUAV, and University of Cambridge. It provides information about the increasing numbers of tourism, particularly day tourists for which concrete estimates is difficult to find. Totals of commuters are also estimated. This also outlines COSES predictions regarding the carrying capacity of Venice—in English.

APPENDIX B – MAP OF ACTV VAPORETTI ROUTES

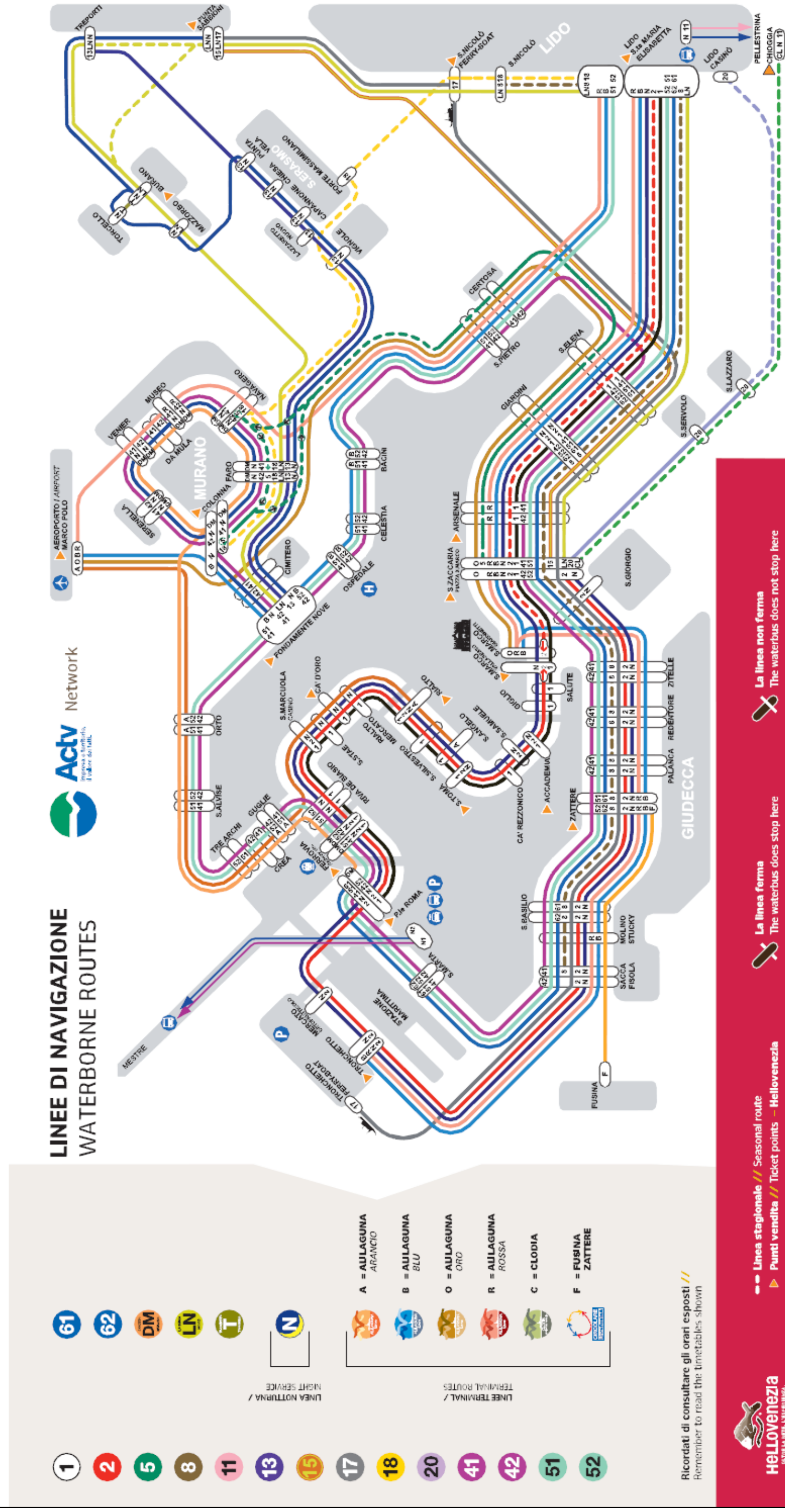


Figure 72 - Map of ACTV *vaporetti* routes

APPENDIX C – CHANGES IN COUNTING LOCATION CHOICES

This team originally planned to count individuals crossing at a number of each type of the three critical flow points between islands: 9 bridges, an undetermined number of *vaporetti*, and all 8 *traghetti*locations. To determine the specific 9 bridges we would count at, we would classify all bridges throughout the city as low, medium, or highly-touristed, based on their proximity to major tourist attractions, depth within residential districts, proximity to entrances to city, and other observations, and also as low, medium, or highly-trafficked overall, taking both tourist and Venetians usage into account. We believed that these criteria would accurately and sufficiently describe bridges for our purposes while considering our time constraints and limited familiarity with the large number of bridges in the city. We could identify a bridge of each of the 9 combinations of these categories and perform counts there, then extrapolate our data to the rest of the bridges throughout the city that fell into those respective categories.

These plans were modified throughout the course of our project. After consultation with advisors, we determined that while both the tourist level and overall usage level of bridges were important distinctions to be made, high volume bridges throughout the city that are used frequently are more pressing to perform counts at than low volume bridges. Though both high and low volume locations would be interesting and informative to study, due to our time constraints we decided that in order to obtain the most immediately useful data, high volume flow points between islands would provide more valuable data for this highly touristed district. Future researchers can supplement our base data with counts at more tourist and popularity levels throughout the city to get an accurate understanding of all types of mobility throughout the city.

Therefore, 20 bridges were chosen. After review and consultation with advisor Carrera and Alberto Gallo, both Venice natives highly familiar with the city's bridges and traffic, four more bridges were added. The list and map of these 24 bridges is as follows.

Table 11 - Original 24 focus bridges

Bridge Name	District (s)	Island to the North	Island to the South	Kept as a Final Bridge in Updated Methodology
Ponte de la Veneta Marina	Castello	99	103	No
Ponte de la Paglia	Castello and San Marco	93	92	Yes
Ponte de la Canonica	Castello and San Marco	92	93	Yes
Ponte de le Ostreghe	San Marco	89	87	Yes
Ponte Sant'Angelo	San Marco	81	83	Yes
Ponte deiBareteri	San Marco	77	92	Yes
Ponte del'Ovo	San Marco	77	80	Yes
Ponte de S. Vio	Dorsoduro	52	53	No
Ponte dell'Accademia	San Marco and Dorsoduro	83	52	Yes
Ponte Novo S. Felice	Cannaregio	18	64	No
Ponte Priuli	Cannaregio	62	64	No

Ponte Ss. Apostoli	Cannaregio	64	69	No
Ponte Cavallo	Cannaregio and Castello	65	66	No
Ponte S. Antonio	San Marco and Castello	77	78	Yes
Ponte de l'Olio	San Marco and Castello	71	77	No
Ponte de le Becarie	San Polo	28	29	No
Ponte de la Madoneta	San Polo	31	32	No
Ponte degli Scalzi	Santa Croce and Cannaregio	20	33	No
Ponte di Rialto	San Marco and San Polo	29	77	Yes
Ponte Papadopoli	Santa Croce	37	36	No
Ponte di Costituzione	Santa Croce and Cannaregio	20	36	No
Ponte de le Sechere	Santa Croce and San Polo	33	34	No
Ponte dei Ragusei	Dorsoduro	44	43	No
Ponte de le Guglie	Cannaregio	15	20	No

Figure 73 – Original 24 focus bridges

However, these plans were again adjusted in order to maximize the level of accuracy we could obtain in our 7-week time in Venice. Rather than collect a limited amount of data for locations throughout all six districts of the city, we decided to collect a more extensive and thorough amount of data for the San Marco district. This would allow us to gain a more accurate understanding of the pedestrian flows for one area, and demonstrate the methodology to be extended to other areas of the city. See methodology section 3.1.1.1 for the list and locations of the final 10 bridges.

APPENDIX D – SUMMARIZED ACTV RIDERSHIP DATA

Stop	Time Bracket	Disembark-ing Totals	Disembark-ing in 15 min	Boarding Totals	Boarding in 15 min	Disembarking and Boarding Total - 15 min
Rialto Riva Carbon SX	7:00-9:00	586	73	393	49	122
	9:00-11:00	1042	130	666	83	214
	11:00-13:00	869	109	969	121	230
	13:00-17:00	1341	84	1553	97	181
	17:00-19:00	718	90	851	106	196
	Full Day	4556	570	4432	554	1124
Sant' Angelo DX	7:00-9:00	595	74.375	197	24.625	99
	9:00-11:00	506	63.25	283	35.375	98.625
	11:00-13:00	387	48.375	372	46.5	94.875
	13:00-17:00	487	30.4375	769	48.0625	78.5
	17:00-19:00	268	33.5	466	58.25	91.75
	Full Day	2243	280.375	2087	260.875	541.25
S.MARIA DEL GIGLIO SX	7:00-9:00	196	24.5	81	10.125	34.625
	9:00-11:00	170	21.25	114	14.25	35.5
	11:00-13:00	198	24.75	179	22.375	47.125
	13:00-17:00	379	23.6875	393	24.5625	48.25
	17:00-19:00	210	26.25	196	24.5	50.75
	Full Day	1153	144.125	963	120.375	264.5
San Samuele	7:00-9:00	0 (not operating)	0 (not operating)	0 (not operating)	0 (not operating)	0 (not operating)
	9:00-11:00	135	16.875	68	8.5	25.375
	11:00-13:00	104	13	109	13.625	26.625
	13:00-17:00	199	12.4375	265	16.5625	29
	17:00-19:00	85	10.625	166	20.75	31.375

	Full Day	**523**	**65.375**	**608**	**76**	**141.375**
VALLAR-ESSO DX	**7:00-9:00**	**183**	**22.875**	**80**	**10**	**32.875**
	9:00-11:00	**289**	**36.125**	**374**	**46.75**	**82.875**
	11:00-13:00	**158**	**19.75**	**622**	**77.75**	**97.5**
	13:00-17:00	**352**	**22**	**1147**	**71.6875**	**93.6875**
	17:00-19:00	**145**	**18.125**	**528**	**66**	**84.125**
	Full Day	**1127**	**140.875**	**2751**	**343.875**	**484.75**

APPENDIX E – CHANGES IN COUNTING METHODOLOGY

To record the number of pedestrians crossing bridges, this team originally planned to use TI-89 graphing calculators. When writing the counting program for the calculators, we utilized two programs in particular: one which returns the specific key stroke pressed and one which returns the time stamp of the button press. We planned to record these two values for every individual crossing a bridge in the 15-minute time intervals, where every individual crossing corresponded to one button press. However, a number of technical problems were encountered and the program was modified multiple times still without completely successfully solving these problems. See Appendix X for the stages of code with full detail of problems. We also ran into human limitations that necessitated modifications to the amount of data collected. Therefore, we adjusted the overall methodology of field data collection. Calculators were used for a portion of data collection and supplemented by mechanical clickers. See Appendix X for the final calculator program code.

The first calculator function used, called GetKey, returns the key code of the key pressed. A keycode is the calculator's stored number for each button that does not correspond to the button labels on the physical calculator. Lists of these keycodes could be translated into pedestrian types using an access database counting query after upload to the computer. For each 15-minute data collection session in the field, a separate list was created to store the key codes representing individuals crossing during that time period.

E.1 STORING TIME STAMPS

The second function, called GetTime, returns the timestamp of each button press. We initially programmed the calculators to store the time stamps of each button press as text values, called strings, since this option would reduce the number of separate locations data needed to be stored in; rather than a separate list to store the hour, minute, and second of each time value as would be required if we used a non-string format, one list could contain all values in the string format HH:MM. For each 15-minute time session, the key codes were stored in one list and the time string was stored in a similarly named list for easy match-up. However, the problem encountered with timestamping data with this was the inability of the TI Connect software to sync any type of string data with a computer. We were unable to access any of the time data stored in the calculator without manually inputting all values from calculator to phone. Another problem was one calculator's unpredictable and unexplainable time reset during a data collection session, when it reset its internal clock to midnight in January 1, 1997.

To address these time problems, we decided that after the full day of base data collection to determine time brackets, the specific time of each pedestrian crossing became too insignificant enough to require developing a new code with a new time storage format or a solution to the calculator's inability to convert string data into a computer-compatible format. With careful record keeping of the 15-minute time period and 2-4 hour time bracket, further time stamping was unnecessary and therefore dismissed from the calculator program. Only total numbers of individuals crossing within the 15-minutes was important; not the specific point in time that each separate individual crossed.

E.2 STORAGE SPEED

The second major technical issue encountered was the slow speed of storage of each of the button presses. This was due to the calculator program's core storage method: each time a button was pressed, this key value to be saved was added to a local-memory list. To then permanently store the value to a list that could be accessed by a computer, this local-memory list was saved, in its entirety, to a permanent list. When the next value was recorded in the local-memory list, the local-memory list would then be again saved, in its entirety, to the permanent list. This repetitive copying of lists significantly and fatally slowed our data collection beginning around the collection of 100 points and rendered any data collected after that nearly completely invalid since some button presses did not get recorded at all if the calculator was still saving the previous button press. To rectify this, we implemented the augment function which adds one point to the list each time. Though this too slows after a number of points are collected, it can function much longer (closer to 300-350 points) before slowing noticeably. Since the peak number of individuals crossing during our full-day counts at *Ponte Sant'Antonio* was 326, this was not an ideal program speed but was functional for the bulk of the data. Further storage speed increases were attempted but storing to matrices, the seeming solution, proved even slower than copying local to permanent lists.

Together, the augment function and elimination of time stamping allowed much faster and more acceptable data storage. Furthermore, since after the full day of base collection, all subsequent collection sessions would be 15 minutes and we would be unlikely to exceed speed of storage capabilities.

During a full day of counts at Ponte Sant'Antonio, the original non-augment program was used. Calculators showed increased storage speed and three calculators performed acceptably. However, after 4 hours of use one of the calculators lost all stored memory on it, including those 4 hours of data and the counting program itself. This was likely due to a low battery. Mechanical clickers were used to finish that day and the lost counts performed again.

After these final setbacks resulting from calculator use, this group was hesitant to rely heavily on calculators. This in conjunction with the same level of ease inputting data from a calculator and data from a written field form led us to collect all counts using mechanical clickers. Since each team member focused on one direction at a time, only two separate entities (tourists and Venetians) needed to be recorded which could easily be done with one mechanical clicker in each hand.

APPENDIX F – FINAL CALCULATOR PROGRAM

Get key function for TI-89
Press "on" to quit this cycle
Program using augment function:
:aug1()

```
:Prgm
:ClrHome
:ClrIO
:DelVar a
:Local a
:Dialog
:DropDown “Select Session”,[“s0”,”s1”,”s2”,”s3”,”s4”,”s5”,”s6”,”s7”,”s8”,”s9”,”s10”,”s11”,”s12”,”s13”,”s14”},a
:EndDlog
:Disp “Start collecting”
:
:If a=1 Then
:list3->s0
:ElseIf a=2 Then
:list3->s1
:ElseIf a=3 Then
:list3->s2
:ElseIf a=4 Then
:list3->s3
:ElseIf a=5 Then
:list3->s4
:ElseIf a=6 Then
:list3->s5
:ElseIf a=7 Then
:list3->s6
:ElseIf a=8 Then
:list3->s7
:ElseIf a=9 Then
:list3->s8
:ElseIf a=10 Then
:list3->s9
:ElseIf a=11 Then
:list3->s10
:ElseIf a=12 Then
:list3->s11
:ElseIf a=13 Then
:list3->s12
:ElseIf a=14 Then
:list3->s13
:ElseIf a=15 Then
:list3->s14
:EndIf
:
:Loop
:getkey()->k
:While k=0
:
:getkey()->k
:EndWhile
:
:k->b[1]
:
:If a=2 Then
```

```
:augment(s1,b)->s1
:ElseIf a=3 Then
:augment(s2,b)->s2
:ElseIf a=4 Then
:augment(s3,b)->s3
:ElseIf a=5 Then
:augment(s4,b)->s4
:ElseIf a=5 Then
:augment(s4,b)->s4
:ElseIf a=6 Then
:augment(s5,b)->s5
:ElseIf a=7 Then
:augment(s6,b)->s6
:ElseIf a=8 Then
:augment(s7,b)->s7
:ElseIf a=9 Then
:augment(s8,b)->s8
:ElseIf a=10 Then
:augment(s9,b)->s9
:ElseIf a=11 Then
:augment(s10,b)->s10
:ElseIf a=12 Then
:augment(s11,b)->s11
:ElseIf a=13 Then
:augment(s12,b)->s12
:ElseIf a=14 Then
:augment(s13,b)->s13
:ElseIf a=15 Then
:augment(s14,b)->s14
:
:EndIf
:
:Disp k
:
:EndLoop
:EndPrgm
```

APPENDIX G – BRIDGE COUNTING FIELD FORM

Date: December 1						Date: December 1				
Counter: Matt						Counter: Marcus				
Direction: Going for all bridges						Direction: Coming for all bridges				
Bridge	Start	End	Tourists	Venetians		Bridge	Start	End	Tourists	Venetians
Ovo	7:15	7:30				Ovo	7:15	7:30		
Bareteri	7:45	8:00				Bareteri	7:45	8:00		
Canonica	8:15	8:30				Canonica	8:15	8:30		
Paglia	8:45	9:00				Paglia	8:45	9:00		
Ovo	9:15	9:30				Ovo	9:15	9:30		
Bareteri	9:45	10:00				Bareteri	9:45	10:00		

Canonica	10:15	10:30				Canonica	10:15	10:30		
Paglia	10:45	11:00				Paglia	10:45	11:00		
Ovo	11:15	11:30				Ovo	11:15	11:30		
Bareteri	11:45	12:00				Bareteri	11:45	12:00		
Canonica	12:15	12:30				Canonica	12:15	12:30		
Paglia	12:45	13:00				Paglia	12:45	13:00		

APPENDIX H – SUMMARIZED BRIDGE COUNTS

H.1 DIAGRAMS OF DIRECTIONS OF TRAVEL

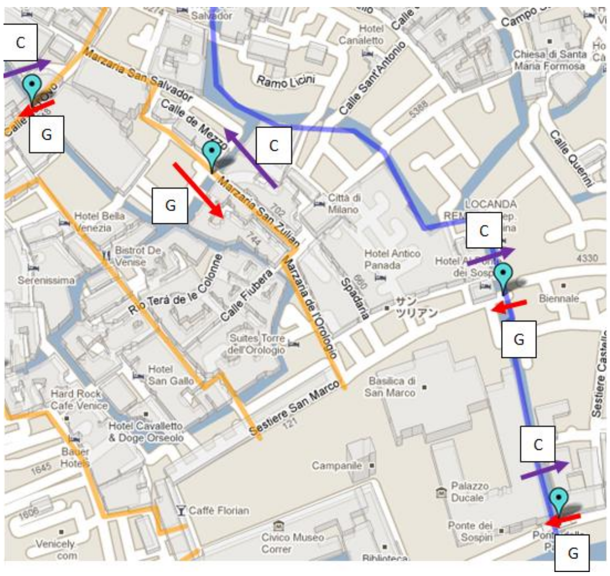


Figure 74 - Directions of travel over Paglia, Canonica, Bareteri, and Lovo bridges

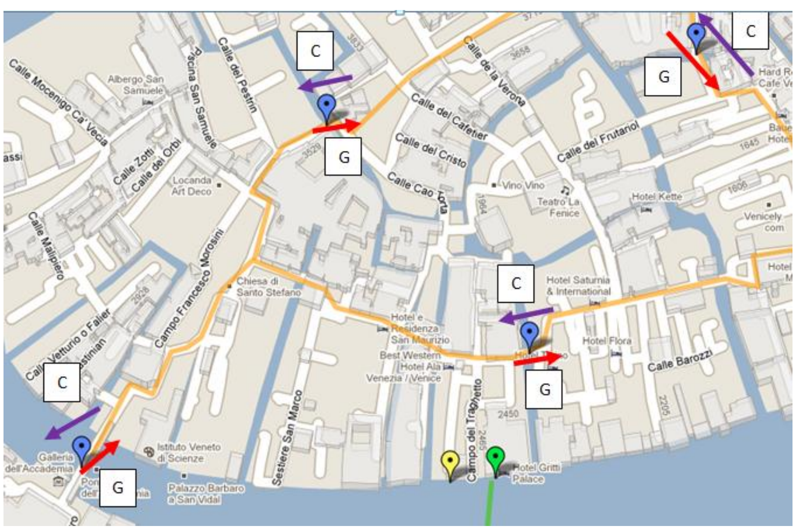


Figure 75 - Directions of travel over Accademia, Fuseri, Ostreghe, and Sant'Angelo bridges

H.2 PONTE DEL'OVO

Ponte del'Ovo										
	GOING is headed towards the Grand Canal and Dorsoduro, from direction of Castello and Rialto									
	COMING is headed towards Castello and Rialto									
Time Bracket	tart Time	End Time	V Coming	V Going	Total V-both dir	T Coming	T Going	Total T-both dir	Total Going-(T+ V)	Total Coming - (T+ V)	Total Everything
Early Morning	7:15	7:30	41	79	120	5	6	11	85	46	131
Morning	9:15	9:30	121	182	303	20	26	46	208	141	349
Mid-Day	11:15	11:30	190	173	363	74	72	146	245	264	509
Afternoon	13:15	13:30	150	129	279	65	51	116	180	215	395
Evening	17:15	17:30	140	102	242	76	63	139	165	216	381
Total			642	665	1307	240	218	458	883	882	1765

H.3 PONTE DEI BARETERI

Ponte del Bareteri										
	GOING is headed towards San Marco, from direction of Rialto									
	COMING is headed towards Rialto, from direction of San Marco									
	Start	End	V Coming	V Going	Total V-both dir	T Coming	T Going	Total T-both dir	Total Going	Total Coming	Total Everything
Early Morning	7:45	8:00	46	97	143	8	16	24	113	54	167
Morning	9:45	10:00	61	103	164	22	37	59	140	83	223
Mid-Day	11:45	12:00	56	95	151	59	65	124	160	115	275
Afternoon	13:45	14:00	54	58	112	65	94	159	152	119	271
Evening	17:45	18:00	30	74	104	58	108	166	182	88	270
Total			247	427	674	212	320	532	747	459	1206

H.4 PONTE DELLA CANONICA

Ponte della Canonica										
	GOING is headed towards San Marco, from direction of Castello									
	COMING is headed towards Castello, from San Marco									
	Start	End	V Coming	V Going	Total V-both dir	T Coming	T Going	Total T-both dir	Total Going	Total Coming	Total Everything
Early Morning	8:15	8:30	47	39	86	6	15	21	54	53	107
Morning	10:15	10:30	65	49	114	31	11	42	60	96	156
Mid-Day	12:15	12:30	72	45	117	31	37	68	82	103	185
Afternoon	16:15	16:30	54	63	117	26	55	81	118	80	198
Evening	18:15	18:30	46	31	77	69	16	85	47	115	162
Total			284	227	511	163	134	297	361	447	808

H.5 PONTE DELLA PAGLIA

Ponte della Paglia										
	GOING is headed towards San Marco, from direction of Castello									

	COMING is headed towards Castello, from San Marco										
	Start	End	V Coming	V Going	Total V	T Coming	T Going	Total T	Total Going	Total Coming	Total Everything
Early Morning	8:45	9:00	35	24	59	51	26	77	50	86	136
Morning	10:45	11:00	33	79	112	133	75	208	154	166	320
Mid-Day	12:45	13:00	31	43	74	117	77	194	120	148	268
Afternoon	16:45	17:00	25	44	69	194	68	262	112	219	331
Evening	18:45	19:00	36	92	128	16	23	39	115	52	167
Total			160	282	442	511	269	780	551	671	1222

H.6 PONTE DEI FUSERI

Ponte deiFuseri											
	GOING is headed towards San Marco, from direction of Rialto and the Grand Canal										
	COMING is headed towards Rialto and the Grand Canal (north) from Campo San Marco										
	Start	End	V Coming	V Going	Total V	T Coming	T Going	Total T	Total Going	Total Coming	Total Everything
Early Morning	7:15	7:30	5	3	8	0	3	3	6	5	11
Morning	9:15	9:30	24	56	80	15	7	22	63	39	102
Mid-Day	11:15	11:30	29	48	77	29	36	65	84	58	142
Afternoon	13:15	13:30	32	46	78	31	24	55	70	63	133
Evening	17:15	17:30	26	28	54	49	30	79	58	75	133
Total			116	181	297	124	100	224	281	240	521

H.7 PONTE DE LE OSTREGHE

Ponte de le Ostreghe											
	GOING is headed towards San Marco, from direction of Accademia										
	COMING is headed towards Accademia, from direction of San Marco										
	Start	End	V Coming	V Going	Total V	T Coming	T Going	Total T	Total Going	Total Coming	Total Everything
Early Morning	7:45	8:00	25	39	64	2	2	4	41	27	68
Morning	9:45	10:00	44	49	93	31	24	55	73	75	148
Mid-Day	11:45	12:00	45	35	80	61	43	104	78	106	184
Afternoon	13:45	14:00	41	40	81	59	34	93	74	100	174
Evening	17:45	18:00	30	32	62	37	27	64	59	67	126
Total			185	195	380	190	130	320	325	375	700

H.8 PONTE DELL’ACCADEMIA

Ponte dell'Accademia											
	GOING is headed towards San Marco, from direction of Dorsoduro										
	COMING is headed towards Dorsoduro, from San Marco										
	Start	End	V Coming	V Going	Total V	T Coming	T Going	Total T	Total Going	Total Coming	Total Everything
Early Morning	8:15	8:30	65	150	215	24	7	31	157	89	246

Morning	10:15	10:30	50	101	151	38	16	54	117	88	205
Mid-Day	12:15	12:30	45	89	134	30	47	77	136	75	211
Afternoon	16:15	16:30	50	98	148	35	34	69	132	85	217
Evening	18:15	18:30	73	51	124	43	16	59	67	116	183
Total			283	489	772	170	120	290	609	453	1062

H.9 PONTE SANT'ANGELO

Ponte Sant'Angelo											
	GOING is headed towards Rialto and Grand Canal, from Accademia										
	COMING is headed towards Accademia, from Rialto and Grand Canal										
	Start	End	V Coming	V Going	Total V	T Coming	T Going	Total T	Total Going	Total Coming	Total Everything
Early Morning	8:45	9:00	64	88	152	25	6	31	94	89	183
Morning	10:45	11:00	54	94	148	55	28	83	122	109	231
Mid-Day	12:45	13:00	61	72	133	41	32	73	104	102	206
Afternoon	16:45	17:00	92	72	164	65	26	91	98	157	255
Evening	18:45	19:00	52	61	113	31	17	48	78	83	161
Total			323	387	710	217	109	326	496	540	1036

H.10 PONTE DI RIALTO

H.10.1 ALL RIALTO COUNTS

Ponte di Rialto																						
	Coming means traveling from VPC/San Polo into San Marco																					
	Going means traveling out of San Marco into San Polo																					
			V Coming					**V Going**					**T Coming**					**T Going**				
			North	South	Interior	Interior Average	**Total**	North	South	Interior	Interior Average	**Total**	North	South	Interior	Interior Average	**Total**	North	South	Interior	Interior Average	**Total**
Early Morning	8:30	8:45	19		98	101	**145**	46		87	87	**181**	11		12	21	**54**	1		14	15	**28**
	8:45	9:00		25	103				48	86				22	29				12	16		
Morning	9:30	9:45	25		93	85	**139**	45		111	115	**199**	16		38	35	**81**	10		31	37	**57**
	9:45	10:00		29	77				39	119				30	31				10	43		
Mid-Day	11:30	11:45	8		106	91	**130**	24		131	136	**220**	14		101	106	**173**	7		105	106	**133**

	11:45	12:00		31	75				60	141				53	111				20	107		
Afternoon	15:00	15:15	15		71	44	**98**	27		88	84	**165**	28		122	98	**176**	7		96	88	**130**
	15:15	15:30		39	16				54	80				50	73				35	80		
Evening	18:00	18:15	9		48	75	**97**	33		138	133	**221**	7		137	113	**144**	2		108	115	**133**
	18:15	18:30		13	101				55	128				24	88				16	122		
Total			76	137	788	394	607	175	256	1109	555	986	76	179	742	371	626	27	93	722	361	481

H.10.2 SUMMARIZED RIALTO COUNTS

	Total V	Total T	Total Going	Total Coming	Total Everything
Earling Morning	325	82	209	198	407
Morning	338	138	256	220	476
MidDay	350	306	353	303	656
Afternoon	263	306	295	273	568
Evening	318	277	354	240	594
Total	1593	1107	1467	1233	2700

H.11 PONTE SANT'ANTONIO

Ponte Sant'Antonio											
	Coming means traveling from Rialto towards Santa Maria Formosa										
	Going means traveling from Santa Maria Formosa towards Rialto										
	Start	End	V Coming	V Going	Total V	T Coming	T Going	Total T	Total Going	Total Coming	Total Everything
Early Morning	8:45	9:00	105	124	229	19	30	49	154	124	278
Morning	10:45	11:00	172	161	333	36	41	77	202	208	410
Mid-Day	12:45	13:00	125	136	261	82	119	201	255	207	462
Afternoon	16:45	17:00	107	155	262	162	134	296	289	269	558
Evening	18:45	19:00	124	117	241	114	55	169	172	238	410
Total			633	693	1326	413	379	792	1072	1046	2118

APPENDIX I – CHANGES IN MOBILITY IMPAIRMENT METHODOLOGY

The original plan of this team was to collect three major categories of mobility impairments, dependant on whether the individual was a tourist or Venetian: tourist with luggage, Venetian with delivery/cargo cart, or tourist or Venetian with another type of mobility impairment. The last category encompassed every type of mobility impairment not described by luggage or carts since other types of mobility impairments were less indicative of the individual's destination. This final broad category "mobility impairments" could include (not an exhaustive list): canes, wheelchairs, baby stroller, personal wheeled cart typically used by Venetians for groceries, slow movement due to old age, limps, large parcels that slowed movement. Though a baby stroller might suggest some likely destinations (by eliminating work locations, for example), in general this broad list of mobility impairments does not clearly indicate destinations with the same level of certainty that luggage indicates hotel or city border destinations and delivery carts indicate store or warehouse destinations. Therefore we planned to focus on luggage, delivery/cargo carts, and group all other mobility impairments together.

When selecting the divisions of mobility impairments to collect, we evaluated the feasibility of field collection of all of these impairments. Using a programmed scientific calculator allowed us to capture more description about individuals than mechanical clickers with only one button could. However, the number of descriptors we captured was limited by our ability to identify each separate type of mobility impairment as individuals walked by us along bridges in the field, look down as needed and locate the corresponding button on the calculator, and press it without missing any other individuals walking by. In addition to identifying mobility impairments, other critical field observations included tourist-Venetian distinctions and direction of travel, which increased the process time for each individual. The speed with which we could identify and process each individual was further limited by the calculator's slower than ideal storage time (usually less than a second but further described in the Appendix E). To evaluate these maximum data intake and recording levels, and performed preliminary counts using programmed calculators to test the following potential button layout and amount of data.

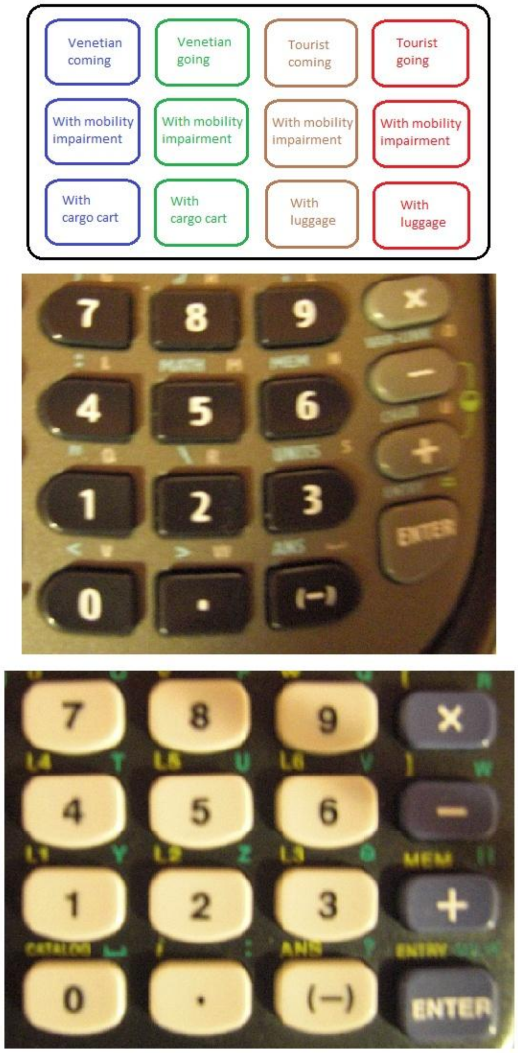


Figure 76 - Proposed programmed calculator buttons to record mobility impairments

We found it feasible for one counter to collect both directions of travel as well as Venetian-tourist distinction. However, we were skeptical about our ability to capture mobility impairments as well as direction and Venetian-tourist distinctions. The preliminary counts were conducted in the evening when pedestrian traffic may not have been at its peak. Therefore, we performed more preliminary counts for mobility impairments in the daytime. This second time, we concluded that it would be more feasible to collect only the presence or absence of a mobility impairment without distinguishing between type of impairment, since recording all this data while also distinguishing tourists from Venetians may lead to errors in our data. Collecting more accurate data divided into fewer categories would be more beneficial than collecting erroneous data, regardless of the number of categories.

Upon review of a 2007 WPI IQP project focusing primarily on mobility impairments in Venice, we definitively decided to reduce the distinction of types of mobility impairments and instead draw upon the data collected by this 2007 team. See Appendix K for the results of this 2007 project.

APPENDIX J – MOBILITY IMPAIRMENT COUNTING FIELD FORM

Mobility Impairment Counts
Day 0 – to determine applicability of 2007 mobility breakdowns
Monday November 15, 2010
Location: Ponte Sant'Antonio
15-minute time intervals from 6 AM to 8 PM
Specific time: _______________; ________________
Counter name: _____________________; _______________________

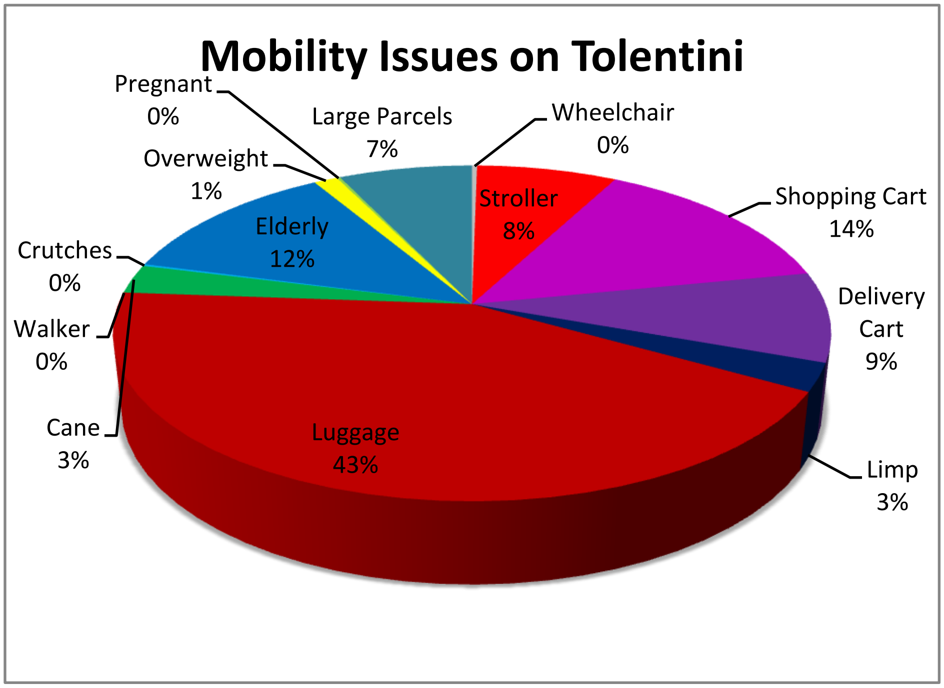
Mobility Impairment	Tally													
	6:00-6:15	6:15-6:30	6:30-6:45	6:45-7:00	7:00-7:15	7:15-7:30	7:30-7:45	7:45-8:00	8:00-8:15	8:15-8:30	8:30-8:45	8:45-9:00	9:00-9:15	9:15-9:30
Wheelchair														
Crutches														
Walker														
Cane														
Limp														
Stroller														
Luggage														
Shopping Cart														
Delivery Cart														
Limp														
Elderly														
Large Parcels														
Overweight*/Pregnant														
Other														

Notes:
____
____
____

*Mark an O for overweight

Only mark subjective categories (limp, elderly, large parcels, overweight/pregnant) if the person is showing signs of duress; if their mobility is visibly impaired

APPENDIX K – 2007 MOBILITY IMPAIRMENT PROJECT RESULTS



APPENDIX L – SUMMARIZED MOBILITY IMPAIRMENT COUNTS

Mobility Impairment	6:00-6:30	6:30-7:00	7:00-7:30	7:30-8:00	8:00-8:30	8:30-9:00	9:00-9:30	9:30-10:00	10:00-10:30	10:30-11:00	11:00-11:30	11:30-12:00	12:00-12:30
Cane	0	0	1	1	0	2	0	4	3	3	6	2	7
Stroller	0	0	0	0	4	5	5	1	3	5	7	9	10
Luggage	4	4	4	3	5	14	11	19	16	18	23	14	47
Shopping Cart	3	1	3	3	12	9	12	18	12	14	9	18	10
Delivery Cart	1	3	0	3	5	12	5	13	11	3	5	2	8
Other	2	0	2	1	0	3	1	2	8	3	4	4	9

Mobility Impairment	13:00-13:30	13:30-14:00	14:00-14:30	14:30-15:00	15:00-15:30	15:30-16:00	16:00-16:30	16:30-17:00	17:00-17:30	17:30-18:00	18:00-18:30	18:30-19:00	19:00-19:30	19:30-20:00
Cane	2	1	5	0	1	2	1	1	1	1	1	0	0	0
Stroller	1	2	0	0	2	6	3	8	6	9	6	6	5	1
Luggage	24	13	6	5	10	15	10	16	13	11	8	5	10	2
Shopping Cart	4	5	5	4	6	5	3	6	5	6	10	2	3	1
Delivery Cart	5	4	6	8	6	1	5	4	1	1	2	1	0	0
Other	3	2	4	3	2	2	1	2	1	2	1	0	1	0

APPENDIX M – SUMMARIZED 2001 CENSUS DATA FOR SAN MARCO DISTRICT

Workers And Residents of San Marco				
Census Tract #	Pop 0-19	Pop 20-64	Pop 65+	TotWorkers
1	0	1	10	35
2	0	7	11	64

Workers And Residents of San Marco				
Census Tract #	Pop 0-19	Pop 20-64	Pop 65+	TotWorkers
3	0	0	0	18
4	4	41	31	247

Workers And Residents of San Marco				
Census Tract #	Pop 0-19	Pop 20-64	Pop 65+	TotWorkers
5	3	2	2	36
6	0	0	4	236
7	0	1	1	13
8	0	0	0	22
9	0	1	2	10
10	8	34	13	302
11	0	1	0	25
12	1	13	3	117
13	4	17	8	75
14	6	13	2	1279
15	0	0	0	0
16	16	62	31	99
17	5	23	4	78
18	0	0	0	73
19	7	39	8	82
20	0	3	0	160
21	0	3	0	184
22	0	7	1	329
23	0	0	0	222
24	0	1	1	0
25	21	85	28	332
26	1	11	7	37
27	0	0	0	109
28	2	6	4	29
29	4	22	8	56
30	3	8	6	17
31	0	7	3	44
32	3	33	22	233
33	0	0	0	0
34	0	0	0	13
35	1	6	2	204
36	2	4	2	38
37	0	0	0	21
38	0	0	0	6
39	2	17	10	213
40	2	7	4	208
41	0	5	3	172
42	0	1	0	16
43	1	14	5	2
44	3	9	4	38
45	0	0	0	4
46	3	17	6	1
47	0	4	4	3

Workers And Residents of San Marco				
Census Tract #	Pop 0-19	Pop 20-64	Pop 65+	TotWorkers
48	0	9	8	33
49	8	42	13	7
50	3	9	3	24
51	0	5	6	0
52	4	9	7	9
53	8	30	11	27
54	5	30	17	221
55	13	70	28	57
56	6	54	26	126
57	0	0	0	10
58	2	13	3	23
59	1	9	1	0
60	0	2	0	13
61	3	8	5	3
62	4	17	13	18
63	0	6	0	26
64	5	33	6	17
65	3	33	18	92
66	1	12	7	0
67	11	60	31	83
68	1	12	7	2
69	11	29	14	13
70	16	47	27	22
71	27	113	61	90
72	8	18	6	5
73	0	0	0	0
74	1	11	10	5
75	7	19	15	186
76	0	2	1	2
77	7	27	13	22
78	4	31	8	22
79	4	12	4	36
80	1	6	4	4
81	10	35	17	15
82	1	18	5	50
83	4	32	13	12
84	2	29	14	24
85	1	11	1	35
86	4	18	15	17
87	1	17	0	8
88	1	7	5	17
89	4	16	7	10
90	6	46	11	50

Workers And Residents of San Marco				
Census Tract #	Pop 0-19	Pop 20-64	Pop 65+	TotWorkers
91	0	4	6	4
92	10	26	12	6
93	1	8	4	5
94	6	11	6	10
95	10	46	13	144
96	4	9	3	34
97	0	7	4	119
98	0	2	4	0
99	0	0	0	180
100	0	13	8	252
101	6	27	11	26
102	3	17	7	13
103	8	26	9	66
104	3	13	5	36
105	3	16	5	4
106	1	9	11	149
107	8	25	9	16
108	7	27	7	25
109	1	10	2	26
110	4	15	7	33
111	5	16	5	32
112	0	18	10	225
113	2	10	4	620
114	2	24	11	102
115	2	7	2	31
116	0	0	0	34
117	1	5	0	97
118	0	0	2	50
119	3	13	1	30
120	0	1	1	119
121	0	1	0	114
122	0	0	2	7
123	9	23	6	139
124	5	25	9	48
125	3	23	8	45
126	3	10	5	7
127	10	56	32	43
128	2	14	5	41
129	1	22	3	83
130	4	12	3	109
131	15	52	32	46
132	1	7	2	75

Workers And Residents of San Marco				
Census Tract #	Pop 0-19	Pop 20-64	Pop 65+	TotWorkers
133	1	8	8	178
134	0	0	0	9
135	2	15	4	35
136	7	22	7	86
137	5	14	2	37
138	3	14	6	44
139	0	2	1	16
140	0	2	1	11
141	6	34	15	279
142	4	30	7	1400
143	5	35	13	49
144	0	9	2	4
145	0	0	2	13
146	0	0	1	22
147	0	7	2	30
148	0	2	0	43
149	6	31	13	326
150	0	5	0	8
151	0	0	0	0
152	7	24	3	121
153	6	25	9	41
154	3	17	7	43
155	5	35	11	328
156	0	6	2	15
157	1	3	4	3
158	0	8	8	4
159	2	10	3	19
160	0	0	0	0
161	13	21	0	205
162	3	17	4	68
163	0	0	0	29
164	1	17	9	113
165	0	4	1	20
166	1	4	0	62
167	1	14	3	49
168	0	0	3	23
169	15	104	30	174
170	1	3	3	17
171	3	16	7	39

APPENDIX N – PEDESTRIAN MODEL PROGRAMMING CODE

```
extensions [ gis ]
globals [ canal-dataset perimeter-dataset paths-dataset island-dataset bridge-dataset building-dataset
        boatstops-dataset  t exits goal?
        current-fillset]
breed [ nodes node ]
breed [ agents agent ]
agents-own [ to-node cur-link speed ]
nodes-own [ exit-distance

  ]

;; ---------- startup/setup/go ----------
to startup ;; called when first loaded
  read-gis-datasets
end

to setup
  clear-all-but-globals ;; don't loose datasets
  ask patches [set pcolor cyan + 3 ]
  setup-world-envelope
  draw-world
  setup-paths-graph
  ;flood-setup
  setup-agents

  let h [round link-length] of links
  set-plot-x-range 0 (max h + 1) ;set-plot-y-range 0 count links with [round link-length = 0]
  histogram [round link-length] of links

end

to go
  ask agents [move-agent speed]
  tick ;; tick called after patch/turtle updates but before plots -- see manual
end

;; ---------- GIS related procs ----------
to read-gis-datasets
  ;;gis:load-coordinate-system "VeniceData/Segmenti_region.prj"
  set island-dataset    gis:load-dataset "Isole_totale_region.shp"
  set bridge-dataset    gis:load-dataset "Ponti_Venezia_CS_region.shp"
  ;;set canal-dataset     gis:load-dataset "Segmenti_region.shp"
  set building-dataset  gis:load-dataset "Edificato_Venezia_CS_region.shp"
  set boatstops-dataset gis:load-dataset "Pontili_ACTV_region.shp"
  set paths-dataset     gis:load-dataset "Grafo_Pedonale_Venezia_CS_B10_polyline.shp"
end
to setup-world-envelope
  let world (gis:envelope-of paths-dataset) ;; [ minimum-x maximum-x minimum-y maximum-y ]
  if zoom != 1 [
    let x0 (item 0 world + item 1 world) / 2          let y0 (item 2 world + item 3 world) / 2
    let W0 zoom * (item 0 world - item 1 world) / 2   let H0 zoom * (item 2 world - item 3 world) / 2
    set world (list (x0 - W0) (x0 + W0) (y0 - H0) (y0 + H0))
  ]
  gis:set-world-envelope (world)
end
```

```
to setup-paths-graph
  set-default-shape nodes "circle"
  foreach polylines-of paths-dataset node-precision [
    (foreach butlast ? butfirst ? [ if ?1 != ?2 [ ;; skip nodes on top of each other due to rounding
      let n1 new-node-at first ?1 last ?1
      let n2 new-node-at first ?2 last ?2
      ask n1 [create-link-with n2]
    ]])
  ]
  ask nodes [hide-turtle]
  ;ask links [hide-link]
end
to-report new-node-at [x y] ; returns a node at x,y creating one if there isn't one there.
  let n nodes with [xcor = x and ycor = y]
  ifelse any? n [set n one-of n] [create-nodes 1 [setxy x y set size 1 set color [0 0 255 50] set n self]]
  report n
end
to draw-world
  gis:set-drawing-color [230 230 230]      gis:fill island-dataset 0       ; For color [ Red Green Blue Opacity]
  ;gis:set-drawing-color [15 0 0 200 ]   gis:draw bridge-dataset 1
  gis:set-drawing-color [0 0 0 85]     gis:fill building-dataset 0
  ;gis:set-drawing-color [0 0 0 155]        gis:draw building-dataset 1
  gis:set-drawing-color [130 50 0 200]      gis:fill boatstops-dataset 0
  gis:set-drawing-color [0 0 0 125]      gis:fill bridge-dataset 0
  ;gis:set-drawing-color [102 204 255]      gis:fill canal-dataset 0
  ;gis:set-drawing-color [  0   0 255]     gis:draw canal-dataset 1
  ;gis:set-drawing-color [255   0   0]     gis:draw paths-dataset 1


end
to-report polylines-of [dataset decimalplaces]
  let polylines gis:feature-list-of dataset                              ;; start with a features list
  set polylines map [first ?] map [gis:vertex-lists-of ?] polylines      ;; convert to virtex lists
  set polylines map [map [gis:location-of ?] ?] polylines                ;; convert to netlogo float coords.
  set polylines remove [] map [remove [] ?] polylines                    ;; remove empty poly-sets .. not visible
  set polylines map [map [map [precision ? decimalplaces] ?] ?] polylines        ;; round to decimalplaces
    ;; note: probably should break polylines with empty coord pairs in the middle of the polyline
  report polylines ;; Note: polylines with a few off-world points simply skip them.
end
to-report meters-per-patch ;; maybe should be in gis: extension?
  let world gis:world-envelope ; [ minimum-x maximum-x minimum-y maximum-y ]
  let x-meters-per-patch (item 1 world - item 0 world) / (max-pxcor - min-pxcor)
  let y-meters-per-patch (item 3 world - item 2 world) / (max-pycor - min-pycor)
  report mean list x-meters-per-patch y-meters-per-patch
end

to flood-setup
  set exits (turtle-set node 10 node 466)                         ;Sets the destinations nodes of the floodfill algorithm
  ask nodes [set exit-distance n-values count exits [0]]
  ask exits [set shape "circle 2"
           set size 9
           set color black
  ]
  set exits sort exits
  set t 0
```

```
  foreach exits [
    flood-fill ?
    set t t + 1
  ]
  ;ask nodes [set label map [precision ? 0] exit-distance]
end

to flood-fill[nodeset]                                    ; a flood-fill algorithm using nodes and there distances apart to set up
shortest distance calculating method.
 if is-node? nodeset [set nodeset nodes with[self = nodeset]]
 ask nodes [set exit-distance replace-item t exit-distance 9999 ]  ; initializes current value of array exit-distance to 9999
 let n nodeset                                            ; sets a variable n equal to the set of patches called (Sinks, Paths,
Corners)
 ask n [set exit-distance replace-item t exit-distance 0 ]         ; Sets all patches being floodfilled to have an exit-distance of
0
 while [count n > 0][
   let nnext turtle-set [link-neighbors with [item t exit-distance = 9999]] of n
         ;creates variable nnext which equals patches surrounding the sink or previously filled patches that are also a
walkway
   ask nnext [set exit-distance replace-item t exit-distance min [item t exit-distance + distance myself] of n]
         ;sets exit-distance of those surrounding patches to 1 higher then the previous value in the loop
   set n nnext                        ; Makes n the newly edited patches
   set current-fillset n
   show count current-fillset
   ;tick
 ]
end


;; ---------- agents procs ----------
to setup-agents
  set-default-shape agents "person"
  let agent-size agent-meters / meters-per-patch
  let max-speed  (max-speed-km/h / 36) / meters-per-patch
  let min-speed  max-speed * (1 - speed-variation) ;; max-speed - (max-speed * speed-variation)
  create-agents num-agents [
    set size agent-size ;; use meters-per-patch??
    ifelse random 100 <= 50 [set shape "person student" set color red ][ set shape "person business" set color green]
    set speed min-speed + random-float (max-speed - min-speed)
    let l one-of links
    set-next-agent-link l [end1] of l
  ]

end

to move-agent [dist] ;; agent proc which also describes how the select
  let dxnode distance to-node
  ifelse dxnode > dist [forward dist] [
    let nextlinks [my-links] of to-node
    ifelse count nextlinks = 1
    [ set-next-agent-link cur-link to-node ]
    [ set-next-agent-link one-of nextlinks with [self != [cur-link] of myself] to-node ]
    move-agent dist - dxnode
  ]
end
```

```
to set-next-agent-link [l n] ;; agent proc
  set cur-link l             ;; current link selected for next step forward
  move-to n
  ifelse n = [end1] of l [set to-node [end2] of l] [set to-node [end1] of l] ;the end and
  face to-node
end


;; ---------- One-Liners ----------

to clear-all-but-globals reset-ticks ct cp cd clear-links clear-all-plots clear-output end

to-report mid-nodes report nodes with [count link-neighbors = 2] end
to-report end-nodes report nodes with [count link-neighbors = 1] end
to-report hub-nodes report nodes with [count link-neighbors > 2] end


; Notes:
; 1 - There does not seem to be a way to get the location of a vertex in the original GIS space.
;     (I.e. location-of returns netlogo coords.) This could be resolved by a meters-per-patch primitive.
;     SOLVED: Use the world-envelope to find the meters per x cord and meters per y cord.  Very close.  Average.
; 2 - When a polyline dataset is clipped by the world view, it would be nice to have the option
;     of creating vertices on the edge to correspond with the world intersection of the polyline.
;     Similarly, it would be nice to have polygons similarly clipped to the worldview, creating
;     similarly modified polys.

;Things to create (1): Create number of agents based on census tract. Census tract is an array that can be read into
;

;Destination nodes
;- how ?
;- physical node assignment
;-VectorFeature property-name

;Agents
;- bias
;- Bridges need "to apply a force on agents

 ;- weighted selection
```

APPENDIX O – GIS MAPINFO-TRIP FILE CROSSOVER (TOURIST)

O.1 ORIGINS OF TOURISTS

Tourist Trip File: Origins			
ID	**LocationName**	**Type**	**NodeID**
1	Rialto Bridge	Bridge	10426
2	Accademia Bridge	Bridge	10280
3	Hotel Rialto	Hotel	11095
4	Ponte de l'Olio	Bridge	21730
5	Ponte S. Antonio	Bridge	12445
6	Ponte de la Fava	Bridge	12446
7	Ponte de la Malvasia	Bridge	12447

8	Ponte de Ca' Balbi	Bridge	12448
9	Ponte de la Guerra	Bridge	12449
10	Ponte de l'Anzolo	Bridge	12451
11	Ponte del Remedio	Bridge	12452
12	Ponte de la Canonica	Bridge	12454
13	Ponte de la Paglia	Bridge	12455
14	Vallaresso	Vaporetti	10595
15	Giglio	Vaporetti	10194
16	S. Samuele	Vaporetti	10193
17	S. Angelo	Vaporetti	10192
18	Rialto Vaporetto	Vaporetti	10189
19		Hotel	10882
20		Hotel	10083
21		Hotel	11443
22		Hotel	13524
23		Hotel	10353
24		Hotel	11445
25		Hotel	11459
26		Hotel	10104
27		Hotel	11469
28		Hotel	10384
29		Hotel	11481
30		Hotel	10117
31		Hotel	11482
32		Hotel	11469
33		Hotel	11475
34		Hotel	11385
35		Hotel	10365
36		Hotel	10946
37		Hotel	11641
38		Hotel	10167
39		Hotel	11208
40		Hotel	10394
41		Hotel	11179
42		Hotel	11668
43		Hotel	10635
44		Hotel	11272
45		Hotel	10635
46		Hotel	11228
47		Hotel	11293
48		Hotel	11600

49		Hotel	11554
50		Hotel	11556
51		Hotel	11543
52		Hotel	11253
53		Hotel	11161
54		Hotel	10317
55		Hotel	11135
56		Hotel	11004
57		Hotel	10309
58		Hotel	10344

O.2 DESTINATIONS OF TOURISTS

Tourist Trip File: Destinations						
ID	**LocName**	**Type**	**NodeID**	**VisitTime**	**TO-Weight**	**TDay-Weight**
1	Rialto Bridge	Bridge to SM	10019	25	90	95
2	Palazzo Contarini del Bovolo	Palazzo	11161	60	25	5
3	Chiesa S. Bartolomeo	Church	11104	25	20	10
4	Chiesa San Salvador	Church	10023	50	55	30
5	Chiesa della Santa Croce degli Armeni	Church	11440	25	10	0
6	Chiesa di S. Gallo	Church	10122	20	5	0
7	Chiesa di San Zulian	Church	10349	35	30	10
8	Chiesa di S. Basso	Church	10391	20	5	0
9	Basilica di S. Marco	Church	10388	30	80	95
10	Chiesa di San Teodoro	Church	10391	15	5	0
11	Chiesa di San Luca	Church	10049	20	10	0
12	Chiesa di San Moisè	Church	10163	30	10	0
13	Chiesa di San Fantin	Church	10295	25	15	10
14	Chiesa S. Maria di Zobenigo	Church	10203	25	10	0
15	Chiesa di S. Maurizio	Church	11233	20	20	0
16	Chiesa di Santo Stefano	Church	10238	35	45	20
17	Oratorio dell'Annunciata	Church	10415	15	5	0
18	Chiesa di San Vidal	Church	11623	15	20	5
19	Accademia Bridge	Bridge to SM	10280	15	80	75
20	Chiesa di San Samuele	Church	10268	20	15	5
21	Chiesa di S. Benedetto	Church	10401	15	5	0
22	St. Mark's Campanile	Belltower	10383	40	25	15
23	St. Mark's Square	Campo	10386	50	75	100
24	Scuola Grande S. Teodoro	Scuola Grande	10027	90	30	10

25	Teatro La Fenice	Theater	10295	60	30	15
26	Museo Correr	Museum	10381	90	35	10
27	Palazzo Ducale	Palazzo	10390	100	50	60
28	Palazzo Mocenigo	Palazzo	11558	75	25	15

APPENDIX P – CENSUS TRACT-TRIP FILE CROSSOVER (VENETIAN)

P.1 ORIGINS OF VENETIANS

Venetian Trip File: Origins					
ID	**CensusTract**	**NodeID**	**AdultResidents**	**YouthResidents**	**ElderlyResidents**
1	1	10393	1	0	10
2	2	11468	7	0	11
3	3	11468	0	0	0
4	4	11445	41	4	31
5	5	11407	2	3	2
6	6	11398	0	0	4
7	7	10368	1	0	1
8	8	10946	0	0	0
9	9	10948	1	0	2
10	10	10946	34	8	13
11	11	11378	1	0	0
12	15	10390	0	0	0
13	148	11429	2	0	0
14	151	10349	0	0	0
15	12	10354	13	1	3
16	13	13531	17	4	8
17	150	10352	5	0	0
18	149	11422	31	6	13
19	152	11443	24	7	3
20	14	11651	13	6	2
21	20	10977	3	0	0
22	21	11641	3	0	0
23	22	10961	7	0	1
24	23	10394	0	0	0
25	24	10394	1	0	1
26	25	10982	85	21	28
27	127	10135	56	10	32
28	126	11670	10	3	5
29	125	11675	23	3	8
30	30	10134	8	3	6
31	128	11000	14	2	5

32	130	11000	12	4	3
33	129	11008	22	1	3
34	156	11433	6	0	2
35	155	11439	35	5	11
36	157	11431	3	1	4
37	158	10113	8	0	8
38	159	10109	10	2	3
39	19	11014	39	7	8
40	18	10121	0	0	0
41	17	11482	23	5	4
42	16	11471	62	16	31
43	153	11454	25	6	9
44	154	11442	17	3	7
45	134	11084	0	0	0
46	132	11059	7	1	2
47	165	11059	4	0	1
48	164	11094	17	1	9
49	166	11353	4	1	0
50	162	10011	17	3	4
51	161	10871	21	13	0
52	163	10426	0	0	0
53	170	10002	3	1	3
54	160	10006	0	0	0
55	169	10886	104	15	30
56	171	10897	16	3	7
57	168	10893	0	0	3
58	167	10073	14	1	3
59	141	10076	34	6	15
60	142	10917	30	4	7
61	140	10925	2	0	1
62	139	11358	2	0	1
63	136	10029	22	7	7
64	144	10087	9	0	2
65	145	11414	0	0	2
66	143	11418	35	5	13
67	137	10083	14	5	2
68	138	10929	14	3	6
69	147	11430	7	0	2
70	146	11113	0	0	1
71	124	11113	25	5	9
72	135	11047	15	2	4

73	133	11050	8	1	8
74	123	13522	23	9	6
75	122	11081	0	0	2
76	121	10327	1	0	0
77	120	11049	1	0	1
78	119	11040	13	3	1
79	118	10342	0	0	2
80	117	11485	5	1	0
81	115	11009	7	2	2
82	114	11020	24	2	11
83	116	10037	0	0	0
84	100	11156	13	0	8
85	99	11076	0	0	0
86	131	11161	52	15	32
87	97	10323	7	0	4
88	98	11115	2	0	4
89	113	11071	10	2	4
90	112	10328	18	0	10
91	101	10302	27	6	11
92	29	11171	22	4	8
93	31	11177	7	0	3
94	102	11148	17	3	7
95	103	11139	26	8	9
96	32	13518	33	3	22
97	28	10290	6	2	4
98	26	11634	11	1	7
99	27	11183	0	0	0
100	36	11204	4	2	2
101	33	11202	0	0	0
102	35	11208	6	1	2
103	37	10178	0	0	0
104	34	11193	0	0	0
105	40	10632	7	2	4
106	39	11187	17	2	10
107	38	11188	0	0	0
108	47	10226	4	0	4
109	48	11632	9	0	8
110	42	10201	1	0	0
111	41	11273	5	0	3
112	46	10206	17	3	6
113	43	10200	14	1	5

114	45	10203	0	0	0
115	49	11266	42	8	13
116	44	10194	9	3	4
117	50	10208	9	3	3
118	51	11247	5	0	6
119	52	11243	9	4	7
120	53	10216	30	8	11
121	54	11629	30	5	17
122	75	10238	19	7	15
123	55	11289	70	13	28
124	56	11294	54	6	26
125	60	11622	2	0	0
126	57	11628	0	0	0
127	61	10713	8	3	5
128	59	10397	9	1	1
129	58	10399	13	2	3
130	64	11323	33	5	6
131	63	10395	6	0	0
132	62	11626	17	4	13
133	80	11545	6	1	4
134	81	11550	35	10	17
135	77	11604	27	7	13
136	79	10241	12	4	4
137	78	11553	31	4	8
138	65	11590	33	3	18
139	66	11586	12	1	7
140	68	11602	12	1	7
141	69	11556	29	11	14
142	76	11574	2	0	1
143	71	11557	113	27	61
144	74	11561	11	1	10
145	67	11314	60	11	31
146	70	11583	47	16	27
147	72	10270	18	8	6
148	73	11333	0	0	0
149	83	11519	32	4	13
150	85	11527	11	1	1
151	84	10407	29	2	14
152	104	11246	13	3	5
153	105	10417	16	3	5
154	106	11255	9	1	11

155	107	11253	25	8	9
156	108	11491	27	7	7
157	110	10065	15	4	7
158	109	11130	10	1	2
159	111	11121	16	5	5
160	91	10415	4	0	6
161	92	11343	26	10	12
162	82	11493	18	1	5
163	90	11492	46	6	11
164	93	11339	8	1	4
165	94	11335	11	6	6
166	88	11513	7	1	5
167	89	10056	16	4	7
168	87	11515	17	1	0
169	86	13530	18	4	15
170	96	11120	9	4	3
171	95	10052	46	10	13

P.2 DESTINATIONS OF VENETIANS

Venetian Trip File: Destinations			
ID	**CensusTract**	**Node ID**	**Workers**
172	1	10393	35
173	2	11468	64
174	3	11468	18
175	4	11445	247
176	5	11407	36
177	6	11398	236
178	7	10368	13
179	8	10946	22
180	9	10948	10
181	10	10946	302
182	11	11378	25
183	12	10354	117
184	13	13531	75
185	14	11651	1279
186	15	10390	0
187	16	11471	99
188	17	11482	78
189	18	10121	73
190	19	11014	82
191	20	10977	160

192	21	11641	184
193	22	10961	329
194	23	10394	222
195	24	10394	0
196	25	10982	332
197	26	11634	37
198	27	11183	109
199	28	10290	29
200	29	11171	56
201	30	10134	17
202	31	11177	44
203	32	13518	233
204	33	11202	0
205	34	11193	13
206	35	11208	204
207	36	11204	38
208	37	10178	21
209	38	11188	6
210	39	11187	213
211	40	10632	208
212	41	11273	172
213	42	10201	16
214	43	10200	2
215	44	10194	38
216	45	10203	4
217	46	10206	1
218	47	10226	3
219	48	11632	33
220	49	11266	7
221	50	10208	24
222	51	11247	0
223	52	11243	9
224	53	10216	27
225	54	11629	221
226	55	11289	57
227	56	11294	126
228	57	11628	10
229	58	10399	23
230	59	10397	0
231	60	11622	13
232	61	10713	3

233	62	11626	18
234	63	10395	26
235	64	11323	17
236	65	11590	92
237	66	11586	0
238	67	11314	83
239	68	11602	2
240	69	11556	13
241	70	11583	22
242	71	11557	90
243	72	10270	5
244	73	11333	0
245	74	11561	5
246	75	10238	186
247	76	11574	2
248	77	11604	22
249	78	11553	22
250	79	10241	36
251	80	11545	4
252	81	11550	15
253	82	11493	50
254	83	11519	12
255	84	10407	24
256	85	11527	35
257	86	13530	17
258	87	11515	8
259	88	11513	17
260	89	10056	10
261	90	11492	50
262	91	10415	4
263	92	11343	6
264	93	11339	5
265	94	11335	10
266	95	10052	144
267	96	11120	34
268	97	10323	119
269	98	11115	0
270	99	11076	180
271	100	11156	252
272	101	10302	26
273	102	11148	13

274	103	11139	66
275	104	11246	36
276	105	10417	4
277	106	11255	149
278	107	11253	16
279	108	11491	25
280	109	11130	26
281	110	10065	33
282	111	11121	32
283	112	10328	225
284	113	11071	620
285	114	11020	102
286	115	11009	31
287	116	10037	34
288	117	11485	97
289	118	10342	50
290	119	11040	30
291	120	11049	119
292	121	10327	114
293	122	11081	7
294	123	13522	139
295	124	11113	48
296	125	11675	45
297	126	11670	7
298	127	10135	43
299	128	11000	41
300	129	11008	83
301	130	11000	109
302	131	11161	46
303	132	11059	75
304	133	11050	178
305	134	11084	9
306	135	11047	35
307	136	10029	86
308	137	10083	37
309	138	10929	44
310	139	11358	16
311	140	10925	11
312	141	10076	279
313	142	10917	1400
314	143	11418	49

315	144	10087	4
316	145	11414	13
317	146	11113	22
318	147	11430	30
319	148	11429	43
320	149	11422	326
321	150	10352	8
322	151	10349	0
323	152	11443	121
324	153	11454	41
325	154	11442	43
326	155	11439	328
327	156	11433	15
328	157	11431	3
329	158	10113	4
330	159	10109	19
331	160	10006	0
332	161	10871	205
333	162	10011	68
334	163	10426	29
335	164	11094	113
336	165	11059	20
337	166	11353	62
338	167	10073	49
339	168	10893	23
340	169	10886	174
341	170	10002	17
342	171	10897	39

APPENDIX Q – DETAILED APPLICATION FEATURES

Included in this Appendix are numerous images from the smart-phone application visual prototype as well as detailed descriptions of the features shown.

Q.1 GENERAL APPLICATION NAVIGATION

The following menu is atop every screen in the application. It enables the user easy access to all features on the application.

	1. Tap to go back to the previous screen 2. Access to the "Map" feature. 3. Access to the "Ticket" feature. 4. Access to the "Schedule" feature. 5. General settings for the application.

Q.2 APPLICATION "MAP" FEATURES

The map interface will be the first screen to show up as the user opens the application.

First screen that will be shown when the user begins the application.

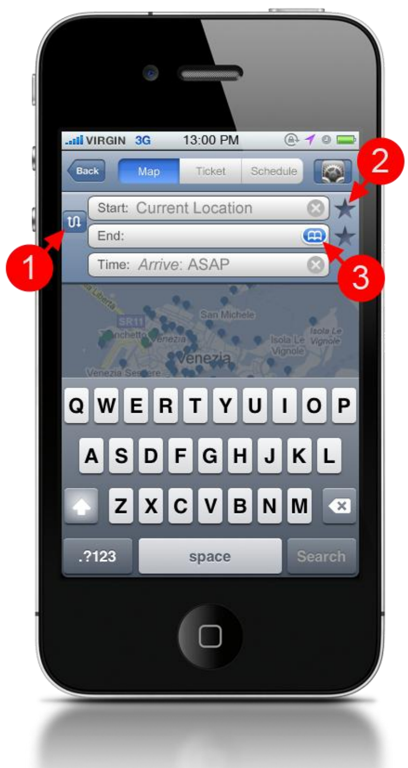
1. The user's current location.
2. The stop the user is closest to.
3. Walking directions to this stop
4. Access to the full boat schedule for this stop.
5. The line and direction the information is being displayed for.
6. Switch the line direction.
7. The time the boat will be arriving.
8. Real-time countdown until the boat arrives.
9. Choose previous/next boats.
10. Set reminder for this boat.
11. Menu for the user's favorite stops, for easy access.

<table>
<tr>
<td>
</td>
<td>1. The map screen will be fully interactive, meaning the user may zoom in/out, pan around, and browse over different on screen features at will.
2. The user can quickly find their GPS location by tapping this button.
3. Access to the Trip Planner feature (see “Trip Planner” below)
4. Toggle between the map and directions the user is currently following (if a route is in progress)
5. Icon that displays the layer overlay options.</td>
</tr>
<tr>
<td>
</td>
<td>After clicking the layers button the following will be available.

1. Toggle to view any “Favorite” saved locations.
2. Toggle to view the boat stops.
3. Menu to toggle individual boat lines
4. Menu to show recent and routes in progress.
5. Menu to other overlays, such as restaurants, tourist locations etc.</td>
</tr>
</table>

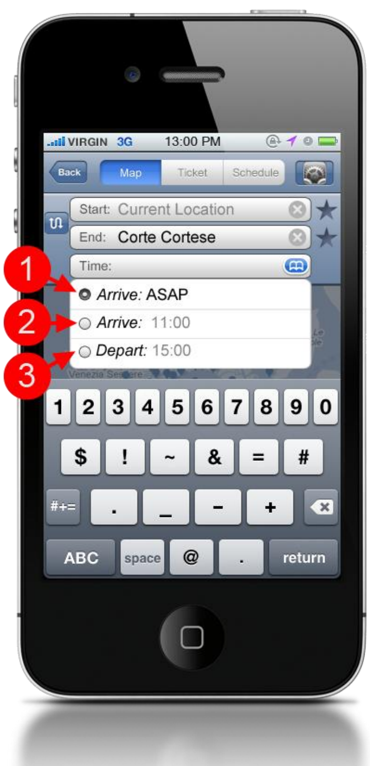
Q.3 APPLICATION “TRIP PLANNER” FEATURES

The trip planner function of the application will give the user complete directions from their starting location to their destination, guiding them every step of the way, if they should choose.



1. Switch starting and ending locations.
2. Save location as a favorite.
3. Access to location options.

<table>
<tr>
<td>


</td>
<td>
1. Option to choose the current location
2. Choose location as boat stop.
3. Choose a location from the map.
4. Saved favorite locations.
5. Previously chosen locations.
</td>
</tr>
<tr>
<td>


</td>
<td>
1. Choose to arrive as soon as possible.
2. Plan route by desired arrival time, where the user will arrive at or before the inputted time.
3. Plan route by departure time, where the route will be determined beginning at the time input by the user.
</td>
</tr>
</table>

<table>
<tr>
<td>
</td>
<td>The application will advise three different routes, available by choosing the different options.

1. Map of route.
2. Route utilizing both walking and the boat.
3. Route featuring the farthest possible distance covered by boat.
4. Walking only route.
5. Choose this route.</td>
</tr>
<tr>
<td>
</td>
<td>Directions for the route.

1. Set reminder for this route
2. Refresh the times.
3. Different legs for the journey. Click to expand and receive specific direations.
4. Required wait at the boat stop.</td>
</tr>
</table>

Expanded boat line information.

1. Current boat location.
2. Number of stops to go.
3. Graphic showing the stops along the line.

Q.4 APPLICATION "TICKET" FEATURES

The "Ticket" feature allows users to purchase and display ACTV boat tickets right from the device.

	1. The user may choose which ticket they wish to purchase. 2. The quantity. 3. And finally complete the transaction. 4. By clicking on the "Scan" tab, they can display the validation code to the ACTV attendant.
	1. The user may browse through their purchased tickets by sliding their finger across the screen, or by 2. Clicking on the "List" button to show the currently valid tickets they have in their possession.

Q.5 APPLICATION "SCHEDULE" FEATURES

The "Schedule" feature allows users to browse the ACTV boat schedule quickly and easily.

	1. Choose the stop to view the schedule by. 2. Save stop as a favorite. 3. Walking directions to this stop. 4. Choose day for schedule. 5. Scrollable input area to view future times. 6. Specific line information. 7. Choose between schedule by stop and timetable for particular boats.

1. Switch line direction.
2. Choose next/previous boat.
3. Time until specified boat arrives.
4. Access to the full timetable.
5. Set reminder.
6. Advisement for this boat.
7. Line graphic
8. Times the boat arrives at particular stop.
9. This particular boat ends the line at the Rialto stop.

Timetable

1. Line information.
2. Hour.
3. Minute.
4. Current time.
5. Time boat arrives, for this example it is 00:18 (12:18am).
6. Caution sign indicates that this particular boat doesn't continue along the entire line.

Q.6 APPLICATION “REMINDERS” FEATURES

Three different reminder options are available throughout the application. A reminder to leave on a journey, reminder to disembark the boat as the user approaches their desired stop, and reminder to advise the user to speed their walking speed up if they are in danger of missing the boat at their current pace.

<table>
<tr>
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<td>
Pop up that recommends user leave in order to catch the specified boat.

1. Time until boat arrives.
2. Defer to next boat.
3. Set reminder (if not set already for later boats).
4. Disregard this notification.
</td>
</tr>
</table>

<table>
<tr>
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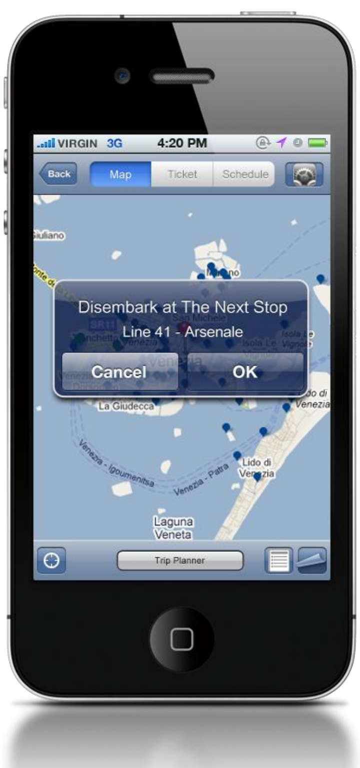
</td>
<td>If the user is travelling at a pace that is too slow, the application recommends they speed up, and will vibrate on a tempo to set an appropriate pace for the user to catch the boat.

1. Time until the boat leaves.
2. The user's location.
3. Path to the boat stop.</td>
</tr>
<tr>
<td>
</td>
<td>Disembark Reminder. The application will notify the user when the next stop is their indicated stop for disembarkation.</td>
</tr>
</table>