Venetian Mobility on Land and Sea

An Interdisciplinary Qualifying Project submitted to the faculty of Worcester Polytechnic Institute in partial fulfillment of the requirements for the Degree of Bachelor of Science.

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Venice, Italy

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Abstract

This project quantified, qualified, and analyzed pedestrians in Venice, Italy through counting and observing Venetians and tourists at bridges and boat stops throughout the city. Data was collected manually and electronically at bridges, and solicited from the Venetian public transit authority and the Venetian Census Bureau. This project also qualified, quantified, and analyzed three high-profile public events to assist Venetian city officials with emergency planning. An autonomous-agent computer model was developed to analyze and display the collected data, and to extrapolate usable information to assist city officials with municipal planning in a safe, controlled, and realistic environment.

Authorship

Preparatory research and field work were conducted by all of the members of the group. The bulk of the analysis of the data collected during field work was done by Kara Greenfield with help from Jason Gabriel.

The PowerPoint presentation was compiled primarily by Jason Gabriel. The ideas incorporated into the presentation were developed by all members of the group.

The theory backing up the computer model was developed by Kara Greenfield. The code for the model was written by Christopher Aloisio and Kara Greenfield.

The rough draft of the methodology section was written by Alexander Kelly and was edited by Jason Gabriel. The majority of the rest of the paper was written by Jason Gabriel and Kara Greenfield. Jason Gabriel was responsible for the majority of the editing with assistance from Alexander Kelly. Final compilation of the report was complete by Kara Greenfield and Jason Gabriel.

Table of Contents

Table of Figures

Executive Summary

Venice is a city like any other, plagued with deep rooted issues in the fields of transportation, demographics, and business. Overcrowding in the streets and public thoroughfares impact emergency response and risk management approaches, and heavy traffic in the unique Venetian canal system erodes the city's already crumbling urban foundation. The lack of effective solutions to the problem of Venetian mobility is due in large part to a lack of understanding of the city's dynamics, and a lack of city-wide data on pedestrian and boat movement. Previous studies have attempted to generate increased knowledge about the most elemental workings of the city's traffic; however, these efforts were focused on small areas and did not analyze the city as a whole. This study of Venetian mobility explored the city as a whole by observing traffic on some of the most important bridges throughout Venice. This project also analyzed passenger data from the Venetian public water transportation authority.

Figure 1 – Street Construction in Venice
An important application of a mobility model

Contrary to popular belief, Venice is not one single island, but a cluster of over 100 islands, separated by canals and connected by foot bridges. Pedestrians must traverse at least one bridge or embark on a boat in order to move around the city beyond the confines of each small island.

To collect the data required for this city-wide analysis, pedestrians were counted using a custom program written for graphing calculators. Over 700,000 pedestrians were counted at bridges over a 5-week period using the calculator method, making this project one of the largest pedestrian studies of this city. The highly accurate time-stamped and categorized data ensured usability of the staggering amount of data, and allowed for the creation of highly accurate graphical models of pedestrian traffic over bridges in Venice. As each pedestrian was counted, their location, direction of travel, time they crossed the bridge, and pedestrian type (Venetian or tourist) was also recorded.

Bridges, however, are not the only way to move around the city. In addition to crossing bridges to move among the 128 islands of Venice, public transportation boats, known as *Vaporetti*, are used to travel from one part of the city to another. The public transportation system in Venice, managed by Venetian Public Transportation Authority (known as ACTV), mirrors many subway systems in American cities, with multiple lines and predetermined stops throughout the city. Data about the number of pedestrians riding the *Vaporetti* was solicited from ACTV for integration into this analysis of Venetian mobility. The combination of the pedestrian counts and ACTV data comprises the vast majority of quantifiable movement within the city.

Publicly available maps and census data collected by the Venetian city government complimented the mobility data required to complete this portion of the project. The synthesis of this collected and acquired data allowed for a broad Venetian Mobility analysis considering far more data points than any previous study.

Figure 2 – Scaffolding Placement
Another significant area of pedestrian mobility analysis

Figure 3 – Space appropriation for restaurant tables, another use for a mobility model

Using the data generated from counting at each of 28 bridges, several analyses of multiple data sets were created, including total hourly traffic flow, flow ratios of Venetians and Tourists at points throughout the city (shown in Figure 4), and the interplay of pedestrian traffic over bridges with the flow of pedestrians through the public boat system. The synthesis shows the expected results of high tourist flows across bridges in commercial areas, and smaller traffic flow comprised of primarily Venetians in the residential areas of Venice.

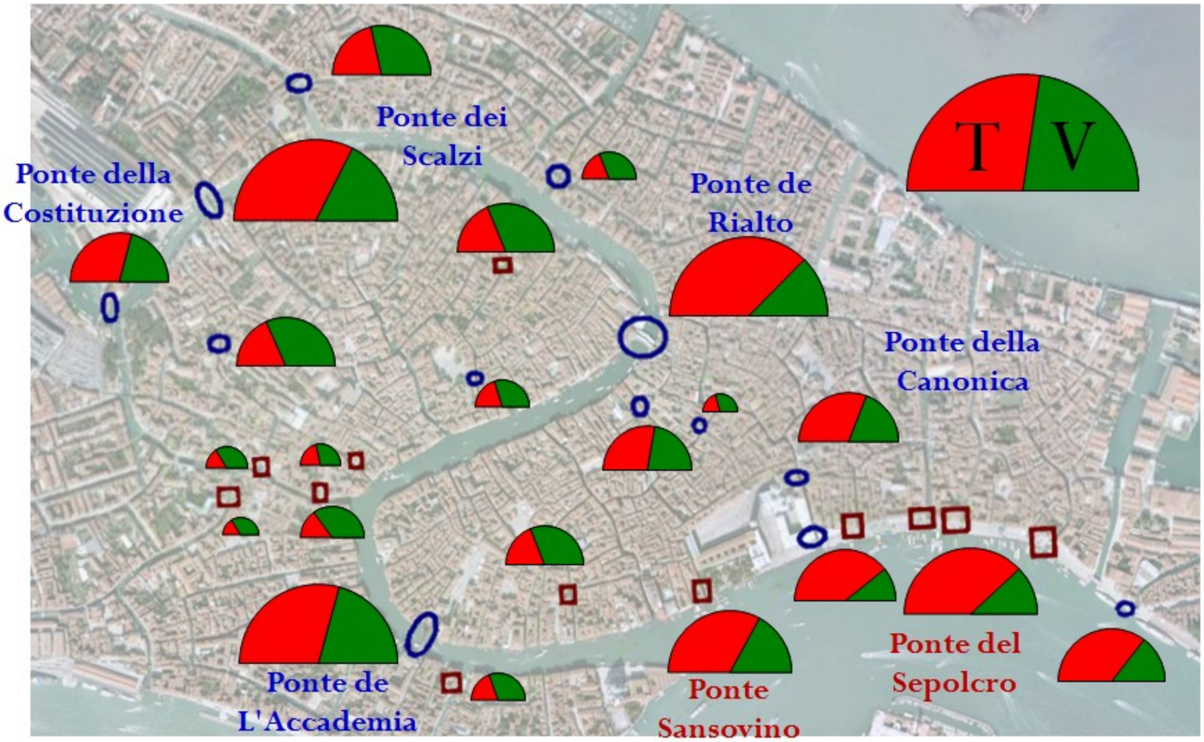

Figure 4 – Map of Venice depicting Pedestrian Volume and Ratios
The size of the half-pies represent the average volume of pedestrian traffic (pedestrians per hour), and the size of the divisions represents the ratio of Venetians to tourists crossing each bridge.

In addition to the analysis of pedestrians on boats and bridges, we analyzed pedestrian traffic at special events and venues throughout Venice. The exclusively pedestrian nature of Venice makes large public gatherings and meeting spaces a unique challenge to city planners. The evacuation of these large public spaces in case of an emergency is also of great concern to Venetian emergency workers and city planners.

First, the famous *Piazza San Marco* was observed to determine how many people populate the square, and how they flow from entry to exit. To study the square, wide-angle time-lapse photographs were taken throughout the day and GPS tracks were recorded to study behaviors of tourists and Venetians. This resulted in a quantification of the sheer volume of pedestrians in the square during this time of year, and a qualification of how these people tend to move. This data was then used to create a computerized evacuation model to demonstrate the predicted flow of pedestrians (and possible inefficiencies in their path) in the case of an emergency evacuation. A preliminary evacuation model had already been created prior to this project, but the extensive data collected will provide the system with more intelligent and realistic behavior. Large-scale special events are occasionally held in this massive square, and a better understanding of the dynamics of large crowds in this location could greatly aid emergency responders and police in planning for such events.

The second special event observed was the Venetian Cemetery, the island of *San Michele*, on All Souls Day (November 2nd). Many Venetians go to this secluded island cemetery by boat on All Souls Day and, just as in the *Piazza San Marco*, if an emergency evacuation were to become necessary, emergency responders would need to move thousands of pedestrians off the island using only the two boat stops and *Vaporetti*, making *San Michele* an ideal location to study a solely water-based evacuation plan.

The third special event studied was the *Festa della Salute*, a Venetian holiday celebration observed every year on November 21st at *La Chiesa della Santa Maria della Salute* (the Church of St. Mary), one of the most popular and famous churches in the city. On the day of this festival, Venetians and tourists enter the church to light candles, and then cross to the neighboring island to purchase and sweets and other food in a carnival-like atmosphere. Just as with the *Piazza San Marco* and *San Michele*, the pedestrian attending the event were quantified and categorized (using mechanical counters instead of the traditional electronic method). This area was studied for the entire day, and eight hours of time-lapse videos were recorded to better understand the flow of pedestrian to and from the island by bridge and by boat. A preliminary evacuation model was created for *Salute* as well, as an example of how these can be helpful in predicting pedestrian movement at special events.

The sheer amount of data collected in this project is staggering, allowing for results beyond a standard numerical analysis. With a base of over 3 million data points, this project aimed at creating an interactive graphical computer simulation of the movement of people through the city of Venice. This interactive model could then be used to predict the flow of pedestrian and boat traffic throughout the city in nearly any situation.

This model will be able to use the data that has been collected both in this project and in future analyses to place autonomous computer representations of the entire city's population and visitors. These digital "people", known as Autonomous Agents, are able to act and move as real people would. The model is a reasonable approximation of reality, and can be used by city planners and other government officials to benefit Venice in a multitude of ways. Emergency response, public space management, and large- and small-scale construction planning are possible uses of this model. Although the coding of this interactive model is not fully completed, it is computationally functional, and includes a detailed plan for its completion by a future Mobility study group. This model proposes to simplify city planning on all levels, and will help Venetian city planners in numerous ways.

In addition to the regular pedestrian model of the city, with a small amount of effort, the model can be transformed into an evacuation simulator. The three special events detailed above are prime candidates for the evacuation model, as they are varied types of situations that all receive a high amount of traffic. The model can assist the city in the event of an emergency and provide a better understanding of the flow of pedestrian traffic through the city.

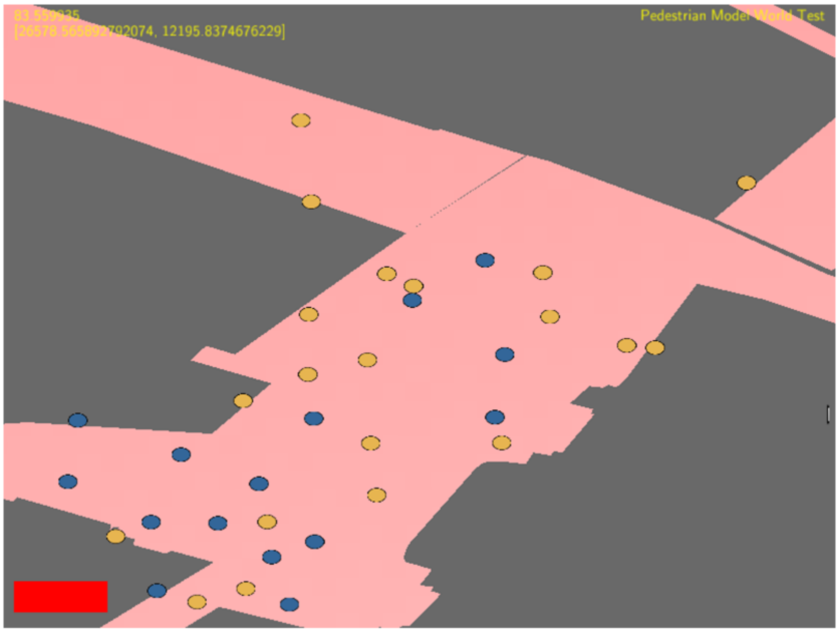

Figure 5 – Preliminary Model of Venice
Zoomed in for detail

This project included the collection over 3 million data points to further the understanding of pedestrian mobility in the city of Venice. In addition to this data, modeling of the entire city with its inhabitants and visitors has begun. With the understanding that each project is a continuation of previous work, the data and analysis produced by this project has greatly contributed to the current body of study on Venetian mobility.

Acknowledgements

The Venice Mobility 2009 IQP group would like to acknowledge several people and organizations which contributed to the success of this study of Venetian mobility: Dr. Daniel Gibson and Dr. Fabio Carrera of Worcester Polytechnic Institute for their invaluable guidance and motivation throughout the preparation and execution of this study; Stephen Guerin of Redfish Group in Santa Fe, NM for consultation and insight on autonomous agent modelling; Franco Fiorin of the ACTV for providing usage data from Venice's public transit system; and Alberto Gallo and Andrea Tassinari for logistical support for project materials and everyday life in Venice.

1 Introduction

Globally, there are billions of commuters who travel regularly, spending a total of 37 million hours (or 4200 years) commuting every day. Most commuters of the world travel by way of roads and sidewalks specifically designed to transport a large number of people as quickly as possible. This data is easy to analyze and can therefore be easily modeled in almost any situation. This is true of almost every city on the planet, with one notable exception.

There are 6.7 billion people in the world[1], and only 62,000 residents of Historical Venice[2]. In an area that is less than 3 square miles (smaller than New York's Central Park), Venice's average commute time rivals the global average. Venice, however, achieves this statistic without any automobiles. Rather than cars, Venice uses boats; instead of conventional automobile-based avenues, Venice has squares and *calli* (pedestrian walkways); and instead of a booming metropolis, tourists outweigh residents twenty-to-one. Compounding the problems created by these unique aspects of mobility, Venice is also being literally eroded away by its primary form of transportation. The uniqueness of Venetian mobility not only provides charm and intrigue, but is also the sources of the city's problems and concerns.

Due to these unique issues, there have been a number of studies on the city of Venice and its boat traffic, most notably by the Venice Project Center (VPC) of Worcester Polytechnic Institute in recent years. Many of the VPC projects have dealt with studying and examining aquatic traffic in the city at major intersections. These studies have been conducted through the tedious task of counting individual boats by hand and tracking specific movements through targeted intersections. Also, one square, *Campo San Filippo e Giacomo*, has been extensively analyzed in the same manner, with the results of this study presented as a limited agent-based pedestrian model applicable to public safety, route management, and public space rental. This data, however, only exists for one public square, or *campo*. The efficacy of this model is further limited by the consideration of only one location over a short period of time.

Boat traffic data has been collected and analyzed as well, but it lacks a useable platform for distribution. Excepting the simple computer model of *Campo San Filippo e Giacomo*, there is no way to

[1] (Wikipedia 2009)
[2] (Wikipedia 2009)

illustrate or apply the pedestrian and boat data that has been collected. Though the means of data collection have been explored, the area of data presentation remains a relatively virgin field.

This project focused on using existing boat traffic analysis methods to generate a new model of pedestrian traffic, which has been incorporated into a cohesive visual representation of Venetian mobility. Obviously, it was not feasible to count pedestrians continuously at every location, nor could every person on every boat have been counted. Instead, targeted data collection and careful analysis were used to extrapolate meaningful information. This procedure produced the most cost effective, time-efficient, and accurate result. From that point, the data gathered and studied was used to create an easily understandable computer visualization using proven systems like the *Redfish*[3]-designed agent-based modeling program. The model represents only the technical aspect of this project. Though it is a major component, the model is not the only facet of this project, as it would be unrealistic to assume that the entire scope of this project could fit within the allotted seven-week term. To ensure continuity for future studies, the advanced methodology was created to be used in continuing studies of Venetian mobility. Undoubtedly, as future projects contribute to the work that was completed by the Venetian Mobility 2009 study, the possible applications of the data will continue to grow. For example, public space can be managed more effectively, and the allocation of those precious spaces can be determined with greater detail than ever before. Currently, many restaurants lease the street-space in front of their establishments from the city to be used for outdoor seating. These *plateatici* can be very beneficial for the local businesses, but tend to obstruct pedestrians who must walk around them. By better understanding the impact of these *plateatici* on pedestrian movement, Venetian city planners can establish a more efficient method of pricing and distribution for this contested ground, generating revenue for the city and governing seating for restaurants based on the pedestrian density at their location. This model can also be applied to noncommercial ends; in applications ranging from the preparation of city evacuation plans to route management for emergency responders and the public works department. This project can benefit the city in many ways, but only after fully considering the social and political uses of the collected data. This project has been able to define movement in the city of Venice better than any other studies of Venetian mobility. This data should be used to assist with the remedies to the problems that plague the city. Without a better understanding of the issues that trouble the city, any potential solution would be frivolous.

[3] http://www.redfish.com/

2 Background

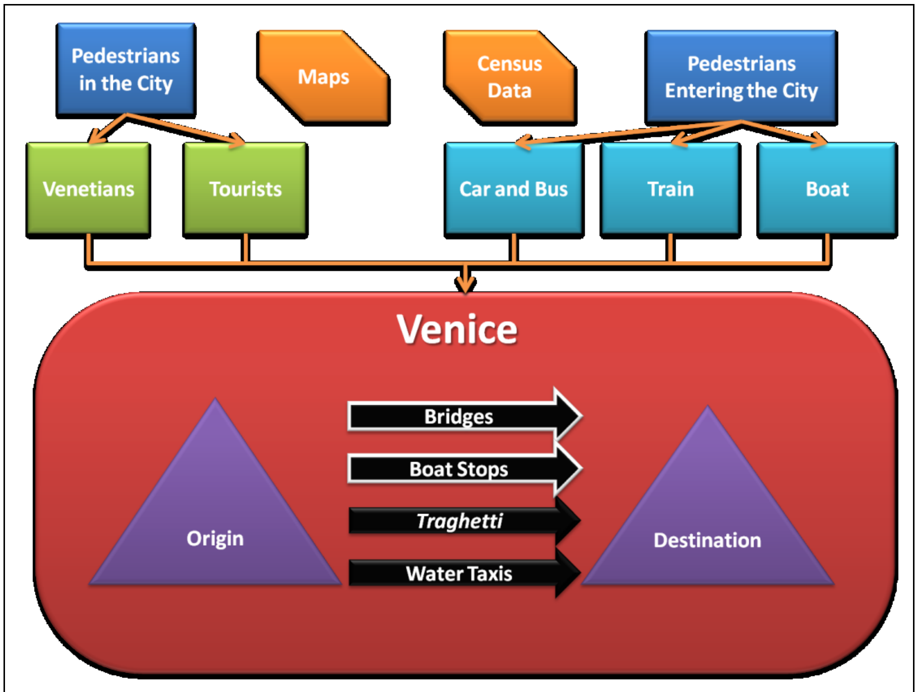

Figure 6 – Components required for studying Venetian Mobility

Like any city, Venice projects its identity from the qualities and combinations of people and places that reside within it. From the unique nature of the famous canals to the struggle to balance the detriments and rewards of tourism, Venice is a city like no other.

The concept of mobility in Venice is slightly more complicated than in other cities, but follows a basic template that dictates the format of any mobility studies done in the city. Pedestrians are initially located either in the city or outside the city. Those outside the city must enter by car, bus, boat, or train and, along with those already in the city, can be categorized as Tourists or Venetians. As the pedestrians move around the city from origin to destination, they must move from one island to the next by way of bridges, boat stops, water taxis, and gondola crossings (known as *traghetti*). The vast majority of pedestrians utilize bridges and boat stops to move about the island, making them the most important sets of locations at which to collect mobility data. We were aided by highly detailed maps of Venice and census data from the city government to display the collected information.

2.1 Evolution of Venetian Canals and Walkways

Physical descriptions of Venice are dominated by one unique feature: the 177[4] canals that are to Venice what roads are to other cities. These nearly 45 kilometers[5] of canals crisscross the city, dividing it into 128 islands, and along with pedestrian pathways, are Venice's main medium of transportation. Snaking its way through the city in the pattern of a backwards "S," the Grand Canal is largest and most active canal in Venice, making it both the highway and "main street" of Venice. Stretching across the numerous canals of Venice are more than 400 pedestrian bridges[6].

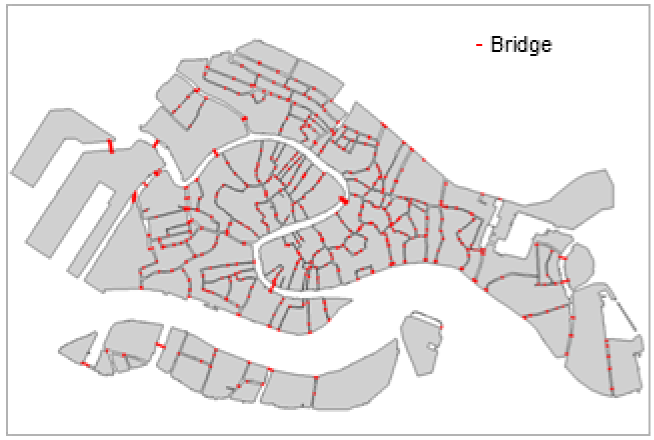

Figure 7 – Map of Venetian Bridges

The shape and nature of this canal system stems from its origins. Originally a series of grassy islands in the middle of a tidal channel, the ancient Venetians inhabiting the individual islands began to dredge the spaces between the islands and use the dredged material to build the islands out and closer to each other, creating a narrow canal system similar to that of today.[7] As a consequence of this natural clustering of Venetians on smaller separate islands, pedestrian movement infrastructure was largely ignored in favor of transportation along the canal system. Over time however, the needs of merchants in the city dictated construction of pathways on land to move goods, and for internal communication[8].

Beginning with the Austrian ownership of Venice in the 1800's, demand for increased pedestrian pathways necessitated the conversion of many of the city's canals into streets and roads, dubbed "rii tera." These new streets, though generally wider than the original walkways, are also generally closer to sea level and more prone to flooding.[9]

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[4] (Morris 1974)
[5] (Morris 1974)
[6] (Encyclopædia Britannica n.d.)
[7] (Carrera n.d.)
[8] (Howard 2002)
[9] (Howard 2002)

2.2 Travel on Canals and Walkways

Figure 8 – A Venetian *Vaporetto*
Vaporetti are so named because they were originally powered by steam (or *vapor*).

As simple as it sounds, transportation networks in Venice move two things: people and the goods those people use. On the canal network, transport of pedestrians is largely delegated to *vaporetti* and other forms of public transportation, while the transportation of goods on the canals consists of cargo boats delivering goods to merchants around the city and garbage boats collecting the refuse from city.

Considering the pedestrian component of transportation, tourists, venetians, and merchants with carts of goods make up the bulk of the traffic.[10] Even in the past, traffic in the pedestrian walkways has been a recognized issue, with special effort made to make sure public space was not infringed upon by new construction or merchants' stalls.[11]

2.3 Demographic Shifts

Tourism in Europe, and specifically Italy's northern city of Venice, has long been popular among Americans and other Europeans. The population of greater Venice has actually decreased slightly from 2003-2007[12], defying the 3.85% increase[13] in the whole of Italy, but the number of tourists in the city has followed its upward trend throughout. On any given day in the peak summer tourist season, the influx of tourists more than doubles the population of the small island city.[14]

[10] (Traffic n.d.)
[11] (Howard 2002)
[12] (Statistiche Demografiche 2009)
[13] (Statistiche Demografiche 2009)
[14] (Gold 2009)

Venice has no roads or cars – the primary modes of transportation for all locals and tourists is walking and the publicly-operated *Vaporetti*, or water busses. With the daily influx of people to the city, the main pedestrian arteries are becoming busier and more difficult to navigate. Despite the slight decline in the number of locals living on the islands, the public transportation system is becoming more and more taxed by the increasing number of tourists visiting and traveling around the city every day. The municipality is well-suited to meet the mobility needs of well more than its local population of over 62,000 people, but the requirements of moving over half a million people around a city only 3 miles wide is taking its toll on the historic metropolis.

The average Venetian spends 31 minutes commuting to work each day[15], rivaling the longest commute time in the United States, New York City's 38 minutes. This figure is presumably greatly inflated by the number of tourists also traveling into and around the city every day.

Figure 9 – City of Venice overlaid on a map of Central Park, New York City

Although the average commute time for a local Venetian seems comparable to that of an American in a big city, it must be considered relative to the size and population of the city. New York City has a population of 8.3 million people and a land area of 305 square miles[16]. Venice, however, with a commute time merely 16% shorter than that of New York City, has 130 times fewer citizens, and at 2.7 square miles[17], covers less than one hundredth of the land area. These staggering statistics show the crippling effects of the influx of tourists on Venice's day-to-day operations.

[15] (Italy Country Commute Time Survey n.d.)
[16] (Wikipedia 2009)
[17] (Hunt 2006)

3 Pedestrian Traffic in Venice

In order to travel between any two points in Venice, at least part of the journey must be completed by walking and for all but the shortest trips, walking in Venice requires crossing bridges. Since walking is as common as it is in Venice, studying pedestrian traffic makes for the perfect starting point in an overall traffic analysis of Venice. Thus, collecting and analyzing pedestrian traffic patterns within Venice was the first objective of this project. Collecting pedestrian data is slightly easier to do in Venice than in various other locations because of how the bridges serve as natural choke points; this knowledge was highly leveraged while studying Venice's pedestrian traffic.

3.1 Pedestrian Traffic Background

The city of Venice performs a census at regular intervals to study the demographics of the city's residents. The census is conducted by dividing the city into survey locations, called *census tract*s (usually several per island), and determining the number and ages of people who live[18] and work[19] in each tract. This data is also used to determine where Venetians start and end their day's movements. Without census data, any study on the city would be severely incomplete and inaccurate, at best.

Other research on Venetian mobility includes studies by the University of Bologna's *Il Laboratorio di Fisica della Città*, or "Physics of the City Laboratory", which studied mobility as affected by the Venetian carnival.[20] Apart from proposals to simulate traffic in the city (much like this IQP has started), *Il Laboratorio di Fisica della Città* also recorded GPS paths of individuals in the city. This study does illustrate particular situations in the city (much like the evacuation models in our project), but the University of Bologna's study falls short of a complete model of the city as our group has planned.

There already exist many piecemeal studies of pedestrians in Venice, but even when taken together, they are by no means a comprehensive overview of Venice's dynamic mobility.

3.2 Pedestrian Traffic Methodology

The study of Venice's pedestrian traffic was two-fold. The first method of study was to as obtain as many raw counts as possible of the number of pedestrians who crossed choke points; this allowed for

[18] (Comune di Venezia 2001)
[19] (Comune di Venezia 2001)
[20] (Harney 2002)

analysis pertaining to the overall dispersion of pedestrians throughout the city. Additionally, the ratio of tourists to Venetians at various locations was determined in order to provide more detailed behavioral information pertaining to the frequencies with which various types of pedestrians can be found throughout Venice.

3.2.1 Programming Calculators to Count Pedestrians

Previous methods of counting people and boats relied on small, handheld mechanical counters (sometimes called "clickers"). This method, however, can only provide simple count data. If any information beyond the number of pedestrians is required, a new way to count pedestrians is required . It was decided that using programmable calculators was a simple and useful method of collecting greater amounts of data.

3.2.1.1 Programming the Calculator

Quantifying pedestrians in its most pure form is a simple proposition, requiring only a person to carry out the counting and a medium for recording the data. For previous projects, mechanical "clickers" were used to count the number of pedestrians who passed a certain point in set period of time. This method only provides a total number of pedestrians at a coarse resolution (no less than five minutes per data set), and gives no information about each individual pedestrian (type of pedestrian, direction of travel, equipment or luggage, etc.). The mandatory increased precision for this project requires a corresponding increase in the precision of the data collected, and dictates a consequent increase in the complexity of the data collection process over previous counting methods. This project required pedestrian counts with real-time data resolution, along with additional data about each pedestrian, including direction of travel and pedestrian type. Instead of the traditional mechanical method, programmable calculators with custom software were used to count pedestrians with the required accuracy and data resolution.

3.2.1.2 Graphing Calculator Devices

Pedestrian counts were carried out using four Texas Instruments graphing calculators: the *TI-89 Titanium*, *TI Voyage 200*, and two *TI-84+ Silver Edition* calculators (see Figure 10, Figure 11, and Figure 12). All three models are custom-programmable, have internal memory capable of storing collected data, and have computer data transfer capabilities over USB (see Figure 16 for a detailed comparison of features).

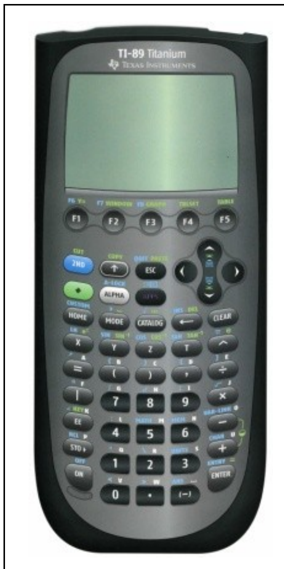


Figure 10 – TI-89 Titanium

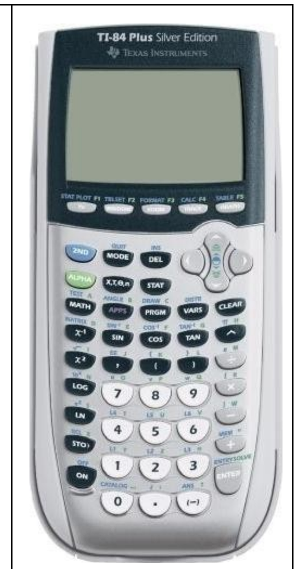


Figure 11 – TI-84+ Silver

3.2.1.3 Custom Software for Calculators

All three calculators are user-programmable directly on the device and remotely from a computer, and use similar programming platforms based on the *TI-BASIC* programming language, which is a derivative of the *BASIC* programming language. The TI-84+ uses the *Z80* Series variant of TI-BASIC, and the TI-89 and Voyage 200 use the slightly more complex *68k* Series variant. Although these two language variants are similar in their syntax and functions, they are not cross-compatible between platforms. The custom software used for pedestrian counts was first coded in Z80 Series on the TI-84+, and was then manually transcribed into 68k Series on the TI-89, and sent via *I/O DataLink* from the TI-89 to the Voyage 200. Despite the slight differences in programming between the two language variants, both versions of the counting software were functionally identical.

Figure 12 – TI Voyage 200

The software used a list-based recording method to store the data input by the counter, with separate lists for each pedestrian type and direction. The human counter would input a number based on the number and type of pedestrians crossing the counting point, and the program stored the timestamp (*Hour:Minute:Second*) as a 6-digit integer in the list corresponding to the type of pedestrian. If the counter indicated multiple pedestrians of the same type passing the point at once, one timestamp entry was made for each person in the appropriate list. The program also output data to the user, including the time, total number of pedestrians counted, number of pedestrians counted in each type-list, and calculator memory information.

The software was revised throughout the project to incorporate suggested improvements from human counters, including the ability to start and stop data collection based on user-specified timestamps, and varying outputs of program status and total pedestrian counts. The majority of these changes were write-speed optimizations and cosmetic improvements to the user interface and, and did not affect the functionality of the code.

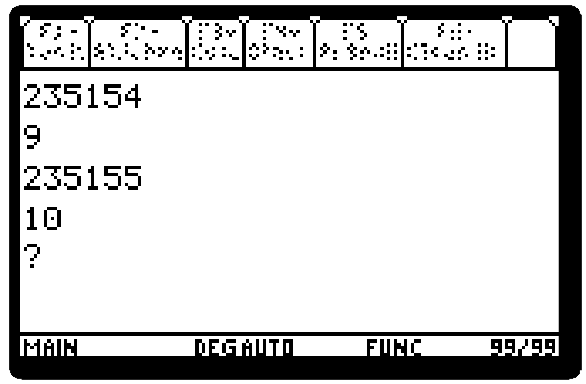


Figure 13 – Raw Data Output on TI-89

3.2.1.4 Calculator Counting Methodology

The human counter stood at one side of the bridge and away from the flow of pedestrians so as not to impede the flow of traffic. Counts were typically taken for two sets of 20 minutes each hour, for two to 18 consecutive hours. Counting pedestrians with the graphing calculators involved the use of the device's number pad (1 through 9 keys), and the "ENTER" key. The keys in the leftmost column of the number pad (1, 4, and 7) indicated pedestrians crossing the bridge in one direction (typically toward the counter), and the keys in the rightmost column (3, 6, and 9) indicated pedestrians crossing the bridge in the other direction. Keys in the middle column were assigned varying special-case functionality based on special circumstances that may exist at a bridge. Keys in the bottom row (1 and 3) indicate one person passing the counting point in a certain direction, and the keys in the second (4 and 6) and third (7 and 9) rows indicated two and three people, respectively (see Figure 14 for a detailed map of the keys on the calculators used in this methodology).

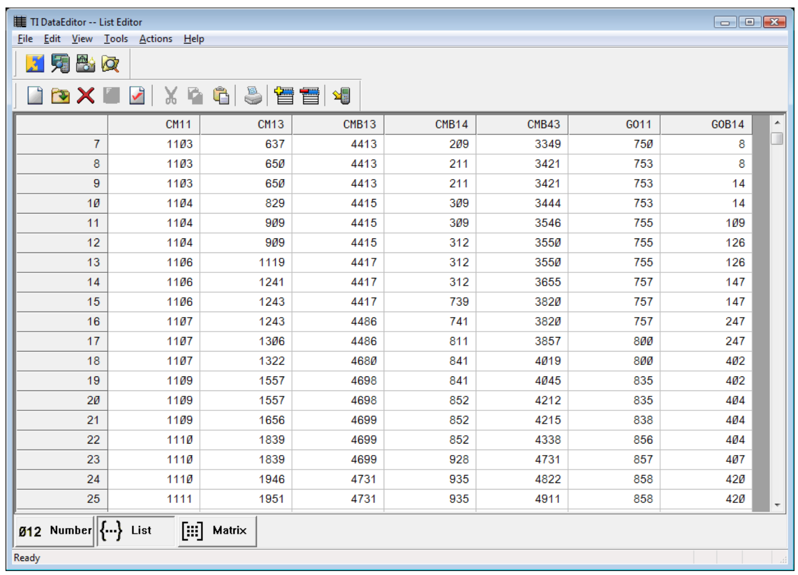
Pressing the "ENTER" key after each digit is pressed submits the entry to the software and logs the timestamp for the corresponding number of pedestrians in the appropriate list. All data displayed on-screen is updated at this time.

Calculator Number Pad	Calculator Keymap				Key Functions			
	7	8	9	x	3 Peds Direct A	Various Functions	3 Peds Direct B	N/A
	4	5	6	-	2 Peds Direct A	Various Functions	3 Peds Direct B	N/A
	1	2	3	+	1 Ped Direct A	Various Functions	3 Ped Direct B	N/A
	0	.	-	ENT	N/A	N/A	N/A	Submit Data

Figure 14 – Calculator Keymap

3.2.1.5 Data Archive and Analysis

Collecting data with calculators makes data archive and analysis very straightforward. All calculator models can be connected to a computer via USB and the lists were transferred using the proprietary Texas Instruments "*TI-LINK*" software and saved as "*.8xl*" files (the standard TI proprietary data-transfer format). *TI-LINK* was also used to combine multiple "*.8xl*" files for each bridge and export the data to Comma Separated Value ("*.csv*") files (see Figure 15). These "*.csv*" files were imported into a pre-prepared spreadsheet template for automatic analysis.



	CM11	CM13	CMB13	CMB14	CMB43	GO11	GOB14
7	1103	637	4413	209	3349	750	8
8	1103	650	4413	211	3421	753	8
9	1103	650	4413	211	3421	753	14
10	1104	829	4415	309	3444	753	14
11	1104	909	4415	309	3546	755	109
12	1104	909	4415	312	3550	755	126
13	1106	1119	4417	312	3550	755	126
14	1106	1241	4417	312	3655	757	147
15	1106	1243	4417	739	3820	757	147
16	1107	1243	4486	741	3820	757	247
17	1107	1306	4486	811	3857	800	247
18	1107	1322	4680	841	4019	800	402
19	1109	1557	4698	841	4045	835	402
20	1109	1557	4698	852	4212	835	404
21	1109	1656	4699	852	4215	838	404
22	1110	1839	4699	852	4338	856	404
23	1110	1839	4699	928	4731	857	407
24	1110	1946	4731	935	4822	858	420
25	1111	1951	4731	935	4911	858	420

Figure 15 – TI-LINK File Converter

3.2.1.6 Limitations and Technical Considerations of Calculators

While the electronic counting solution is far superior for quantifying pedestrians in most circumstances, there exist two major limitations to this technology and methodology.

First is the speed at which data can be recorded. While traditional mechanical "*clickers*" are limited only by "maximum human clicking speed," each calculator's data write-speed the choke point for electronic data recording. This delay also increases proportionally with the amount of data recorded during each counting session. The delay between when a number is submitted on the calculator and when the software is ready to receive a new data point is minimal (less than one second), but can decrease the accuracy of counts in extremely high-volume situations.

Texas Instruments Graphing Calculator Specifications Comparison			
Specification	**TI-84+ Silver**	**TI-89 Titanium**	**TI Voyage 200**
Memory	1.5 MB	700 KB	2.7 MB
RAM	24 KB	190 KB	188 KB
Processor Speed	15 MHz	16 MHz	12 MHz
Key Setup	Numerical	Numerical	QWERTY
Link Capability	USB and TI-I/O	USB and TI-I/O	TI-I/O

Figure 16 – Calculator Specification Comparison

In addition to the hindrance of lag time, device memory can interfere with data collection. While all calculator models have sufficient storage capacity to hold data from over 30 hours of high-volume counting, the devices lack the RAM to manipulate lists with large numbers of entries. The TI-84 tends to return memory errors as list sizes approach 400 entries, and the TI-89 and Voyage 200 can collect approximately 700 data points per list before encountering a memory error. These errors typically do not interfere with 20-minute counting sessions, but quickly archiving used lists and switching to a new set of data lists is a stop-gap solution to these infrequent memory errors.

Also, as with any electronic solution to data collection, additional considerations include battery life, adverse effects due to bad weather, and the expensive and fragile nature of the calculators.

3.2.2 Counting Pedestrians on the Rialto Bridge

Figure 17 – A tourist shop on the Rialto Bridge

The Rialto Bridge is one of the four bridges that cross the Grand Canal, and is therefore an extremely busy pedestrian thoroughfare, especially for tourists. In addition to its prime location and unique scenic view of the city, there are many shops on and around the bridge that cater primarily to tourists, causing a dramatic increase in foot traffic in the area around the bridge. The Rialto Bridge was the first bridge at which pedestrian counts were carried out, and served as a test for methodology that would be used on all other locations. Counts were taken from the north-west side of the bridge using graphing calculators (as described above). The Rialto Bridge also has a unique "three-lane" layout that makes pedestrian counting at this location unique.

3.2.2.1 Quantitative Observations of Pedestrians on Rialto Bridge

Rialto Bridge has an interesting and unique design: the bridge is divided into three lateral sections. Most traffic runs through the larger, middle section due to the size of this path, the directness of the path, and the multitude of stores that are accessible through this space. For the purposes of counting this busy avenue, the middle section was divided into two easily manageable areas, ensuring that all pedestrians would be counted without "double-counting". At any one time, two team members were counting pedestrians on the bridge, one was taking pictures of the bridge and pedestrians for later use, to be described more below, and the fourth team member was recording qualitative observations and assisting the other group members. Only two group members were counting pedestrians at any one time, so only two of the four avenues on the bridge were being counted at any one time.

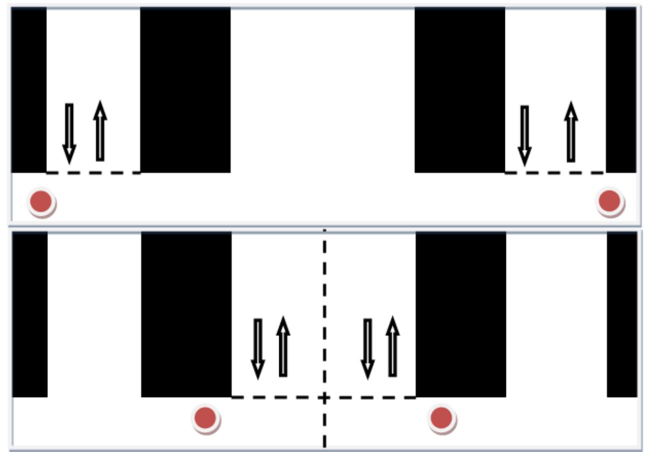


Figure 18 - The east side of the Rialto. The red dots represent counting locations

The counting pattern followed an alternating "20-10-20-10" pattern: both counters would record data in the middle avenue for 20 minutes, then halt counting for 10 minutes while the data lists were saved to the calculator memory and the program reset for the next count. When counting the center avenue of the bridge, one counter would only record pedestrians who crossed the threshold of the bridge on the southern half of the center line, and the other recorded pedestrians who crossed the threshold on the northern half. The counters would then collect data along the two outside avenues (one counter on each avenue) for 20 minutes, followed by another 10 minute break for saving the data and resetting the programs. This 60-minute pattern repeated throughout the day. This counting pattern provided 20 minutes of data for each avenue of the bridge for every hour, and 40 minutes of total flow data for the whole bridge each hour – more than sufficient for extrapolation, analysis, and input into the computer model.

The pedestrian counting was carried out on the custom calculator software, as per the methodology above. As with all bridge counts, the data were divided into two categories (Venetians and tourists) and two directions of travel (north and south in the case of Rialto). These data types provide for greater accuracy in the model when predicting the flow of pedestrians on the bridge.

In addition to using calculators to count pedestrians, pictures were taken at regular intervals to determine the percentage Venetians and tourists on the bridge at any point in time. These pictures were taken on the same days as calculator counts were taken to ensure . The data were then input into a spreadsheet (results can be found in appendix). More information on these percentages can be found in the results chapter of this report.

Figure 19 – Example of the photos taken on the Rialto Bridge

Data was collected on this bridge from 7 AM until 9:30 PM over three nonconsecutive days. This interval captured most of the movement on this bridge, producing a complex graph, as shown below in *Results and Analysis*.

3.2.2.2 Qualitative observations of Pedestrians on Rialto Bridge

Rialto Bridge also has distinctive traffic flow patterns that vary from hour to hour. These patterns were observed manually, and through analysis of pictures taken on the bridge (mentioned above), to add an element of qualitative analysis to the quantification of pedestrians.

3.2.3 Quantifying Pedestrians at other Bridges in Venice

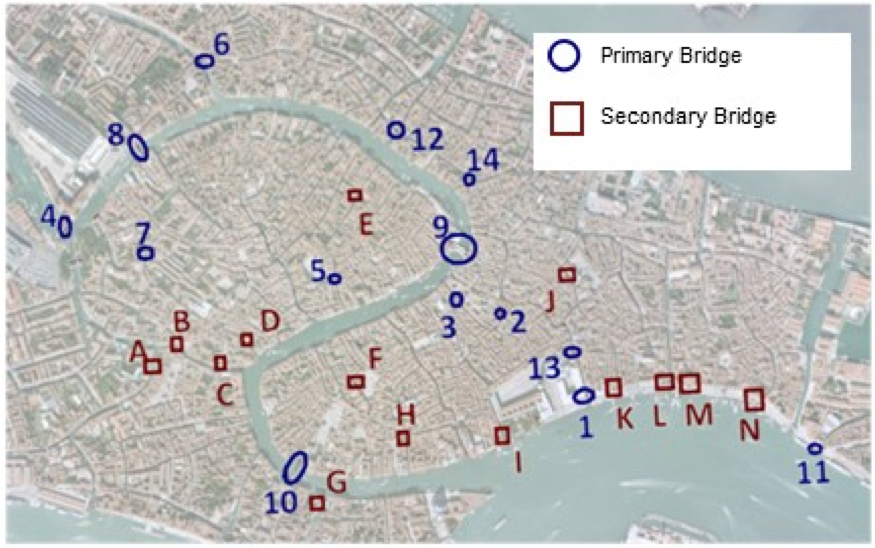


Figure 20 – Map of the 28 Bridges Studied

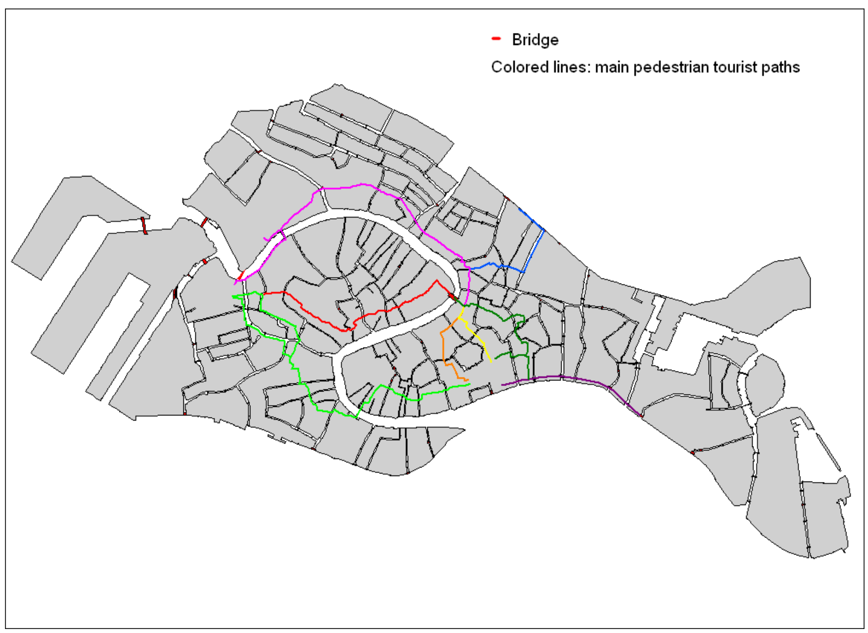


Figure 21 – Primary Pedestrian Tourist Paths

While Rialto is an important bridge, and quite possibly the most complex one, there are over four hundred others that will feed the model. Not all can be counted in a seven week period, and in fact, twenty-eight were chosen for their importance and locations. Most were chosen because they are located on main tourist paths and are consequently valuable for gathering data on tourists. Bridges C, D, E, F, and G are not located on main tourist paths. They were chosen because they are still heavily trafficked and, when taken as a group, are representative of bridges that are predominantly used by Venetians. Not all of these bridges were investigated for a full day's worth of data, but each has been examined in some degree of depth in order to generate a comprehensive model for pedestrian traffic. These bridges were counted using the same methodology as was described for Rialto Bridge, adapted for single-lane bridges (only one counter using one calculator on the same "20-10-20-10" counting schedule).

Digital videos were recorded at each bridge to determine the percentage of Venetians and tourists crossing each bridge, the percentage of each group that was encumbered with bags or carts, and the percentage of each with other mobility impairments such as wheelchairs or canes. For accuracy, three videos were recorded at each bridge. Each bridge had a video taken once on a Saturday, once on a Sunday, and once on a weekday for a general comparison of each day-type. The weekend videos were taken on the same days and times as the weekend pedestrian counts, and the Sunday video collection was taken while it was raining.

3.2.3.1 Weekend Counting Methodology

On November 7th and 8th, data for Saturday and Sunday traffic were examined through spot-counting each bridge for a twenty minute period and recording a five-minute video of the people on the bridge, to determine the percentage of Venetians and tourists at each location. These bridges were counted using the single-lane methodology described above, yielding time-stamped data separated into directional lists. The video was then used to count how many they different types of people crossing each bridge; distinguished pedestrian types were Venetians, tourists, and those with any type of mobility impairment (cane, walker, wheelchair, stroller, cart, etc.).

It was raining during the Sunday count, but Saturday was a sunny and pleasant day, so the difference between the two can be attributed to the difference in weather conditions (producing a set of pedestrian data from yet another useful situation in Venice to be applied to the model). Usable data was collected during these two days, and it can be used to feed an accurate model of the city of Venice.

3.2.3.2 Weekday Counting Methodology

Figure 22 - Snapshot from Video Recorded at Bridge #10

Bridges were divided into two main categories. Bridge Category 1 consisted of the most important bridges (14 bridges in all), including the aforementioned *Rialto* and *Accademia* Bridges, *Il Ponte della Costituzion* and *Il Ponte dei Scalzi* near the parking lot and train station, and *Il Ponte della Paglia*, on the southwest corner of Saint Marks square. Bridge Category 2 contained the secondary bridges studied. These have moderate traffic, and are on fairly important paths, but do not attract the same level of use or importance as Category 1 bridges. A short video was also taken at each bridge on a weekday; in the same way as on the weekend. The video was then used to count how many of different types of people at each bridge were Venetians, tourists, and those with any type of mobility impairment. This video data will be discussed in more detail below.

3.2.3.3 Weekday Counting for Category-1 Bridges

The majority of counting time was devoted to Category 1 bridges. In particular, Academia Bridge was counted from 7 AM to 10:30 PM, and was one of the most heavily studied of these bridges. A greater amount of time was spent on each bridge in this group (as compared to Category 2 bridges), in order to get the greatest amount and accuracy of information.

3.2.3.4 Weekday Counting for Category-2 Bridges

As these bridges were not as important as the other type, a full day of counting is not completely necessary. Instead, counting periods varying from 1 to 4 hours designated for each Category bridge to gain a general understanding of how much pedestrian traffic each bridge supports.

3.3 Pedestrian Traffic Results

All calculator data from bridge counts were compiled into spreadsheets and analyzed both numerically and graphically. The *Ponte della Costituzione* , *Ponte dei Scalzi*, *Ponte de Rialto*, and *Ponte de L'Accademia* (the four bridges spanning the Grand Canal) had a full day's worth of data collected, (7 AM to 10 PM) and all other bridges under study had data collected for shorter periods of time (2-6 hours, depending on location and traffic volume). The data was examined in order to identify hourly trends, and the pure pedestrian counts were tabulated to determine city-wide trends. Pedestrian traffic data for the two busiest bridges spanning the Grand Canal, *Ponte de L'Academia* and *Ponde de Rialto* are presented below.

3.3.1 Ponte de L'Accademia Pedestrian Traffic Results

The Academia Bridge is one of the four bridges spanning the Grand Canal, and is a major thoroughfare between the northern and southern parts of Venice. Below is the data for pedestrians crossing the Academia Bridge over the course of a full business day.

Data collection at the *Ponte de L'Accademia* yielded a characteristic "double peak" shape as seen elsewhere in this mobility study. In relation to the *Ponte de L'Accademia*, this overall shape can be described in several parts. First is the expected increase throughout the morning as tourists and Venetians move out into the city at the beginning of the day. There is a slight spike in the graph centered around 7:30 AM, shortly before most business open at 8 AM. This spike can be attributed to the morning "rush hour" of businesspeople going to their places of employment. Pedestrian traffic steadily increases through the morning as stores open at 9 AM and continues to rise through the lunch hour. The first "peak" on the graph occurs at 12:30 PM as most Venetians leave their offices and tourists leave the tourist attractors to eat lunch. The slight dip immediately after lunch can be attributed to slight decrease in tourist traffic due to the closure of many stores during the early afternoon. Traffic fluctuates, and eventually increases slightly as all the stores and businesses reopen for the afternoon. Traffic continues to increase through the closure of business at 1500, and reaches the second peak at 6:30 PM, just before most shops close for the night. After most businesses and shops have closed, pedestrian traffic markedly decreases through the "dinner rush", and begins to bottom out at 9 PM.

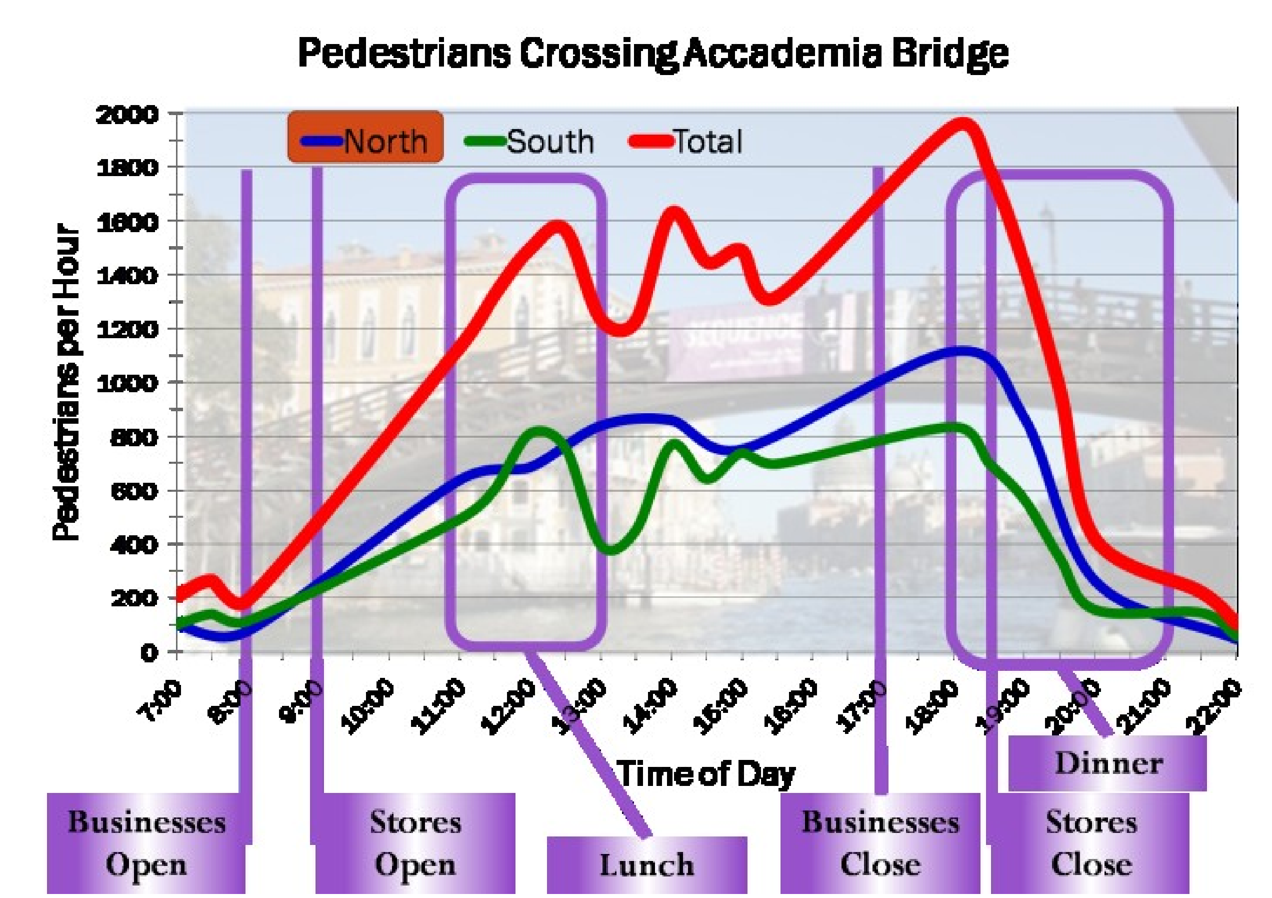


Figure 23 – Pedestrians Crossing Accademia Bridge

Pedestrians crossing the Academia Bridge followed a very simple pattern. Because Academia is a "one-lane" bridge, pedestrians rarely change their path as the cross the bridge, and although tourists occasionally stop to take pictures of the Grand Canal from atop the bridge, they tend to flow across the bridge at approximately the same speed as Venetians.

3.3.2 Ponte de Rialto Pedestrian Traffic Results

Counting pedestrians at the Rialto Bridge presented unique challenges not faced at any other bridge. The Rialto Bridge is separated into three pedestrian lanes that span the Grand Canal, with pedestrians walking across (and between) each lane as they cross the bridge. One counter with one calculator cannot handle the volume of traffic crossing the Rialto Bridge, so two counters were used simultaneously to accurately count pedestrians on Rialto. Two human counters (each having their own calculator), counted pedestrians for 20-minute sessions, switching sessions between the outside and inside "lanes" of the bridge. Each counted recorded pedestrians exclusively on the outside corridors during the outside counting sessions, and each counted pedestrians walking on one half of the center corridor. The data sets collected by each counter were combined in a spreadsheet, yielding a complete traffic analysis of pedestrians crossing Rialto Bridge from 7 AM to 11 PM.

It was observed that from certain ranges of time, individuals on the bridge appeared to be either Venetian or Tourists. From about 7:00 AM to 9:00 AM, the majority of people on the bridge appeared to be Venetian. From then until about 9 PM, there seemed to be a majority of Tourists. This proportion shifted again to favor locals as the night progressed. The pedestrians identified as Venetians were workers with carts and boxes, people in business attire, and schoolchildren, among others. Tourists tended to be those with cameras and suitcases, people who stopped for pictures, or to look out over the water or into shops, and anyone not speaking Italian. More details on the numbers of each, at any given time were found using the pictures taken on these days, and validated the observations from these days.

Il Ponte de Rialto provided an interesting start for the process of pedestrian quantification. It was a successful test of the counting methodology presented above, and provided a large amount of qualitative information and numerical data to be used in this and future projects to determine how people move around the city of Venice.

The data from the study of pedestrian traffic on Rialto Bridge, when compared to the data from the *Ponte de L'Accademia*, suggests that the Rialto Bridge is a much more regulated environment than other bridges, and is less prone to lulls in daily traffic activity. Unique to the Rialto Bridge are the stalls and shops placed directly on the bridge itself, which draw traffic to the bridge itself rather than just to destinations on either side as with other bridges. While more moderated than the *Ponte de L'Accademia*, the traffic on the Rialto Bridge shares similarities to that of the *Ponte de L'Accademia:* pedestrian traffic increases throughout the morning, with a small spike at "rush hour" just before most businesses open. A similar "spike and dip" occurs in early afternoon, and as stores and attractions close in the evening the traffic diminishes accordingly.

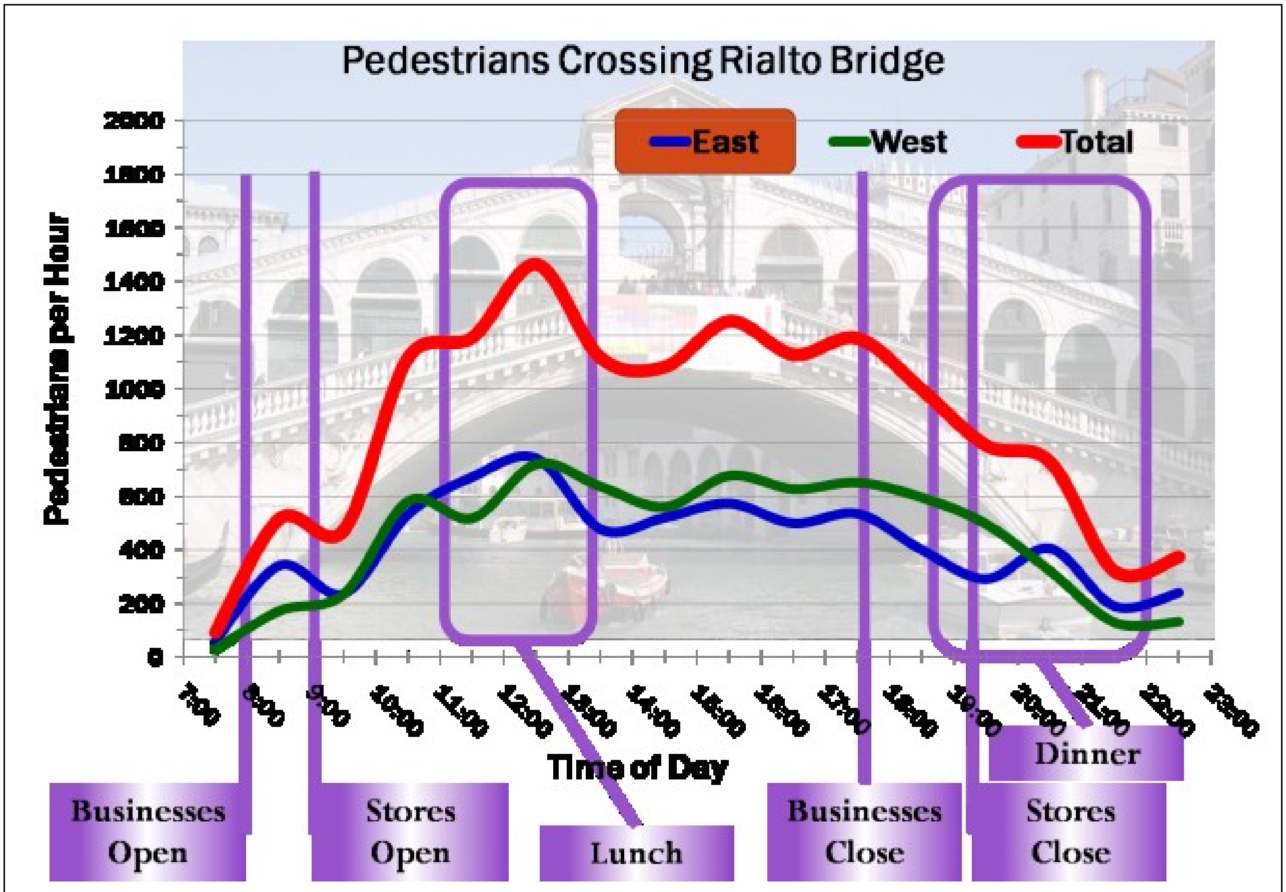


Figure 24 – Pedestrians Crossing Rialto Bridge

Most pedestrians crossing the Rialto Bridge traveled in one of two very distinct ways: the quickest, most direct route taken by Venetians, and the meandering tourists who wander across the bridge from shop to shop. Venetians tended to walk on the outer avenues of the bridge, avoiding the congestion created by the tourist shops, and tourists tended to walk along the center avenue, stopping at the shops as they crisscrossed the bridge.

3.3.3 Dispersion Patterns of Tourists and Venetians

An applicable synthesis of the collected data from all bridges is shown below in the form of a volumetric-based ratio comparison of pedestrian flow. Figure 25 depicts the average number of pedestrians per hour crossing each studied bridge (represented by the size of each half-pie), and the daily ratio of Tourists and Venetians crossing each bridge (represented by the red and green half-pie segments at each bridge below).

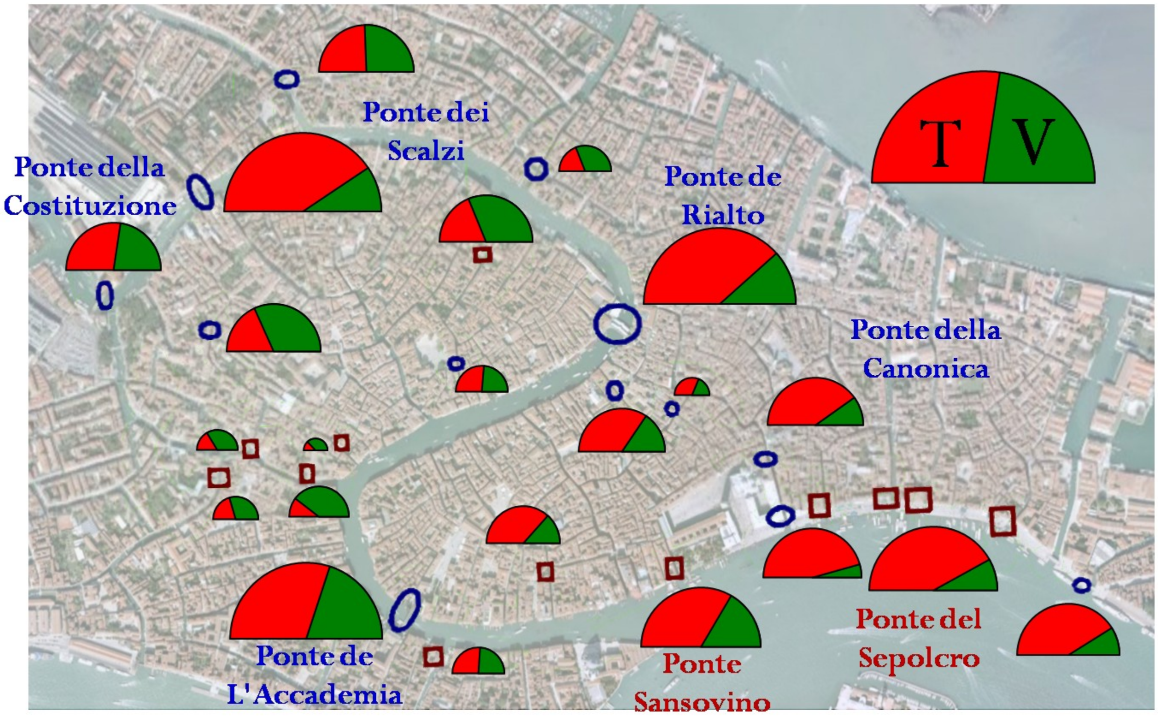


Figure 25 – Map of Venice depicting Pedestrian Volume and Ratios
The size of the half-pies represent the average volume of pedestrian traffic (pedestrians per hour), and the size of the divisions represents the ratio of Venetians to tourists crossing each bridge.

3.4 Pedestrian Traffic Analysis

The most complete data sets were collected for *Ponte de Rialto* and *Ponte de L'Academia*. These bridges were chosen to receive the bulk of attention because of their importance and high level of use. Traffic across these bridges is thus the best possible indicator of the overall flow of traffic through Venice as a whole. Calculations were done to determine the average number of people crossing per minute at multiple points throughout the day, the direction of net traffic flow, and the strength of the net flow. These data are presented in the appendix.

Inspection of these figures reveals many interesting occurrences. The traffic patterns seen across *Ponte de Rialto* are very similar to the patterns that were seen for the ACTV boat catchment basin servicing *Rialto*. This further shows that Rialto is as much of a tourist attraction as it is a bridge. Pedestrians (specifically tourists) traverse *Ponte de Rialto* predominately when its shops are open.

At the beginning of the day, the flow of traffic across *Academia* tends slightly towards the southwest. However, from the middle of the day through the evening, there is a consistent strong flow towards the northwest. This can be attributed to tourists, who do not take the same path in the morning and evening. Many tourists may begin and end their days near *San Marco*, but choose to travel in a counter-clockwise path throughout the course of the day.

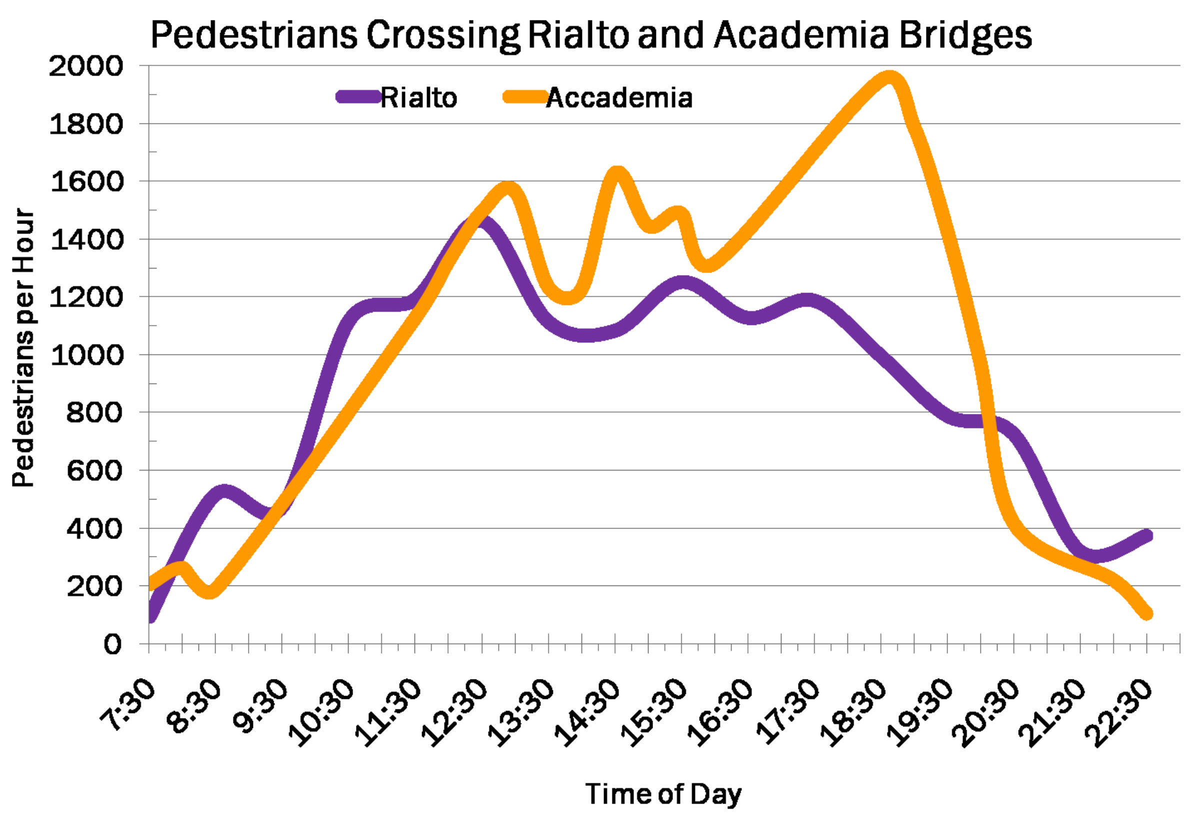


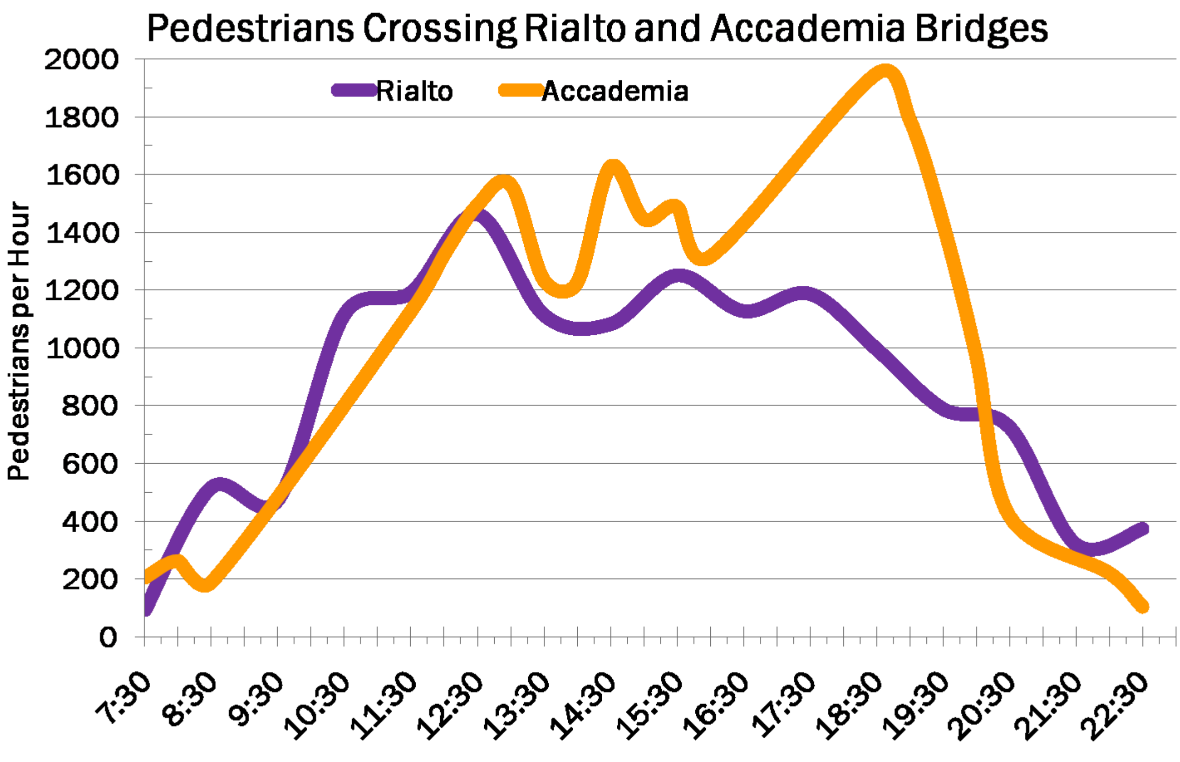
Figure 26 - Pedestrians Crossing Rialto and Academia Bridges

Error! Reference source not found. displays a comparison of Rialto and Academia Bridges. The main points of interest in this graph are that both bridges follow the same general pattern with one exception where Academia experiences a spike at 18:30 while rialto begins its traffic decline. This can be attributed to the fact that Academia services a highly residential area while Rialto does not. Many Venetian workers who are traveling home for the day will cross Academia Bridge at that time.

3.5 Pedestrian Traffic Recommendations

Future studies can use the data collected as a part of this project to greatly simplify future mobility studies. Twenty eight bridges is a reasonable number for an initial study, but these bridges (and others throughout the city) could be studied more in depth. Full day counts at each bridge would be extremely helpful and could provide more accurate data for the model. Also to be considered are the more than 100 other bridges in Venice that are completely lacking any sort of measurement or analysis.

Bridges in the northern and western parts of Venice have not been studied in as much depth as the rest, and are prime candidates for analysis. Eventually, full day counts every each bridge is desired, although of a higher priority is broadening the data set to include at least some data from all bridges in Venice.


Pedestrians Crossing Rialto and Accademia Bridges
Rialto
Accademia
Pedestrians per Hour
2000
1800
1600
1400
1200
1000
800
600
400
200
0
7:30
8:30
9:30
10:30
11:30
12:30
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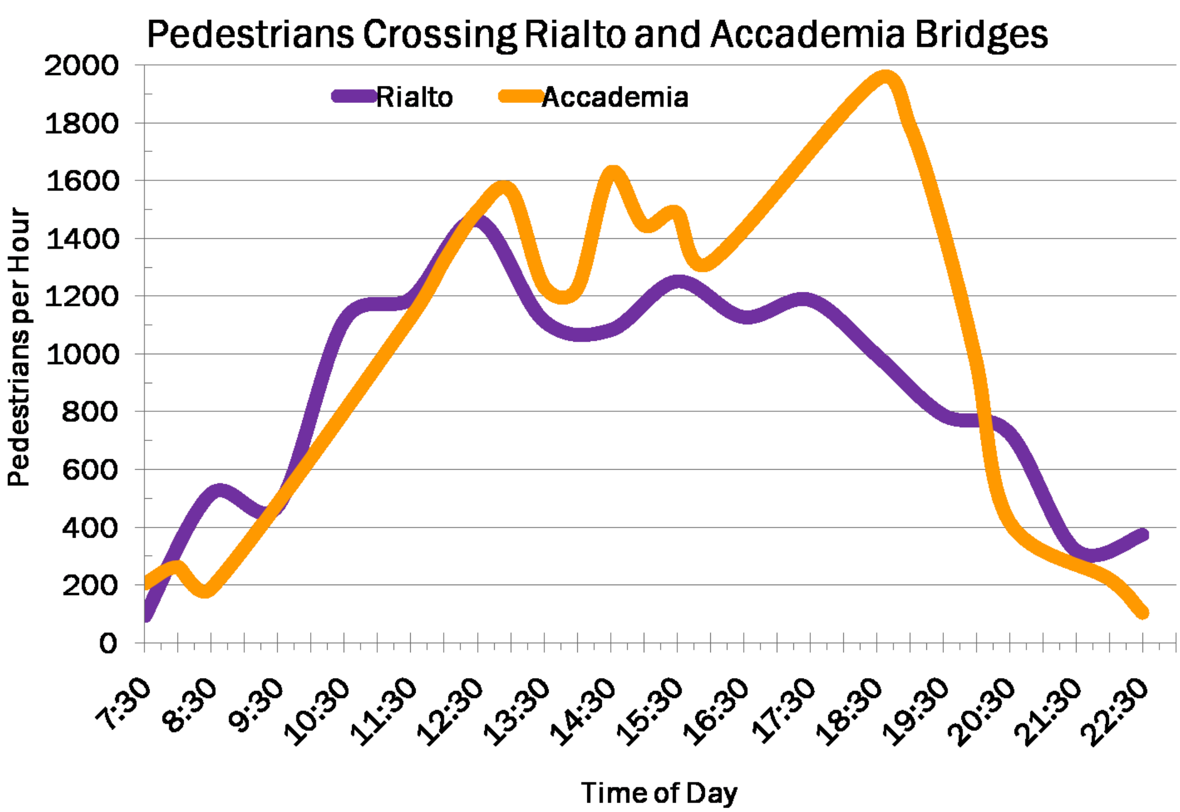

Pedestrians Crossing Rialto and Accademia Bridges
Rialto
Accademia
Pedestrians per Hour
2000
1800
1600
1400
1200
1000
800
600
400
200
0
7:30
8:30
9:30
10:30
11:30
12:30
13:30
14:30
15:30
16:30
17:30
18:30
19:30
20:30
21:30
22:30
Time of Day

4 Boat Traffic in Venice

While travelling in the city of Venice, there are only two methods of mobility. Walking, as it has been discussed, can be reasonably well quantified through the study of bridges. However, there are several boat lines in the city making many stops throughout Venice and the Veneto. Public transportation in Venice, including all land and water busses, is run by the *Azienda del Consorzio Trasporti Veneziano* or ACTV.

4.1 Venetian Boat Traffic Background

Figure 27 – ACTV: the Venetian Public Transportation Authority

As part of their efficiency and management strategies, ACTV surveys the usage of their vehicles throughout Venice and the Veneto, performing routine counts of the number of passengers on *Vaporetti*. This means that there is data available that deals with exactly the information needed for this section of the project. With the assistance of Professor Fabio Carrera, we received this data from Franco Fiorn, a representative of the ACTV.

The Venice Project Center (VPC) of WPI has been studying Venice for over twenty years, and transportation around the city is a significant part of the myriad of topics covered. These studies dealt primarily with boat data. In particular, the IQP from 2007, "*Turning Traffic Around: An Analysis of Boat Traffic in Venice and its Environmental Impacts*" was the culmination of boat traffic work done by the Project Center at this point.[21] The 2007 study took counts at various intersections of the number and types of boats, and observed pollution, noise, and wake amounts by boat type. Similar work had been done in the past by quantifying boats in the canals, and observing various effects of their motion; however, no real work had been completed or attempted in the field of pedestrian traffic by the WPI Venice Project Center until this year. This 2007 IQP also explored the option of using an autonomous agent model to detail how boats move throughout the city in an interactive way. More information on past modeling is detailed in later sections.

[21] (Bilboa, et al. 2007)

4.2 Boat Traffic Methodology

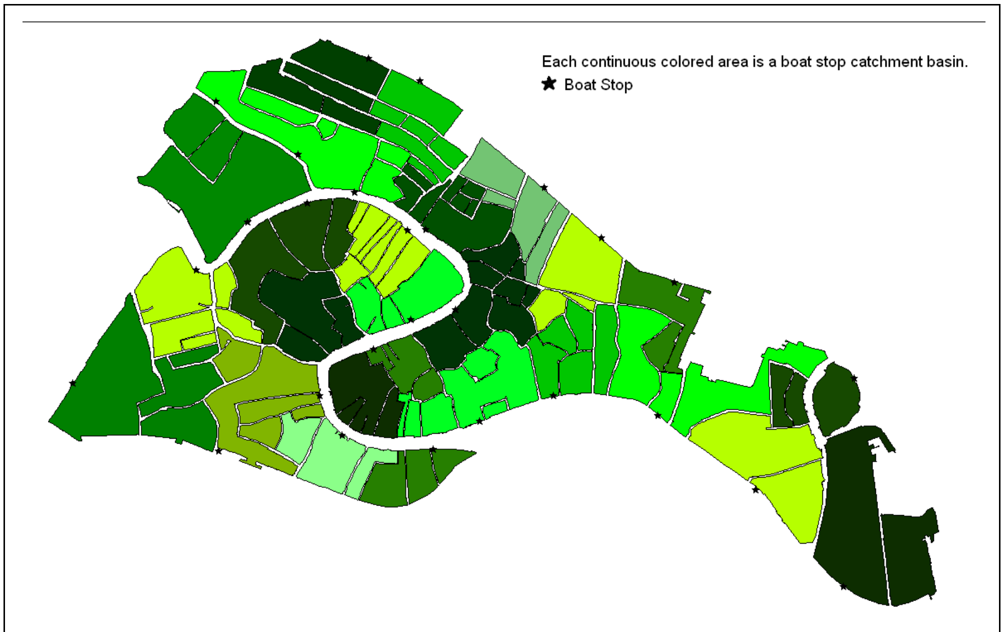


Figure 28 – Collective Catchment Basin

For the heuristic being used, every pedestrian contributes to the traffic flow both in the catchment basin for their origin stop and the catchment basin for their destination stop. Additionally, they most likely do not contribute at all to any areas outside of those 2 catchment basins. The maps shown here were generated by calculating the sum of the number of pedestrians who originate and end at a given catchment basin. Since almost all of the boat trips are less than an hour long, and no shortest path boat trip is more than an hour long, each pedestrian would have been counted twice by the above calculations, so the numbers were all halved in order to obtain reasonable estimates of number of people contributing to traffic at a given point in time. We chose to look at the catchment basins relative to each other as opposed to analyzing the actual numbers of people present in order to make the analysis more representative of other times of the year when Venice would have a different total population.

4.3 Boat Traffic Results

The figures below show the flow of traffic throughout Venice resulting solely from pedestrians who utilize the ACTV boat lines. Darker shades represent a higher volume of pedestrians dispersing to each island and lighter shades represent lower volumes.

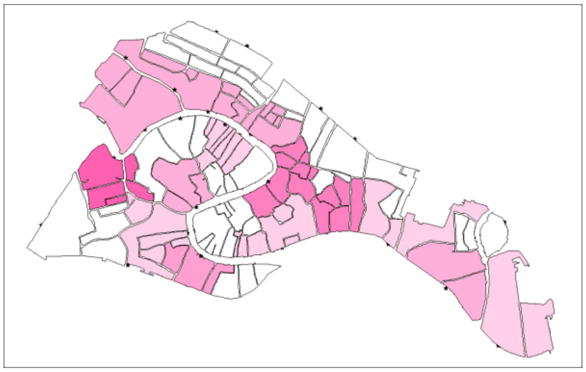


Figure 29 – Pedestrian Dispersion from Boat Stops (12 AM — 1 AM)

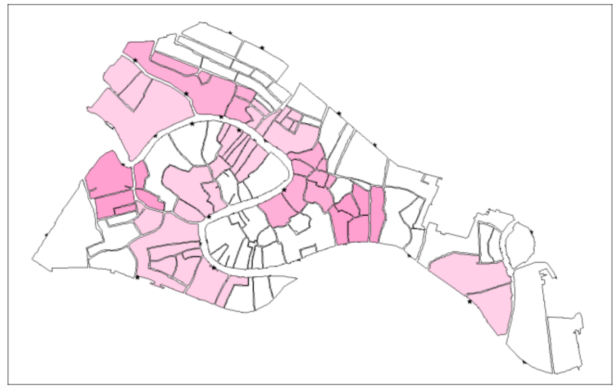


Figure 30 – Pedestrian Dispersion from Boat Stops (1 AM — 2 AM)

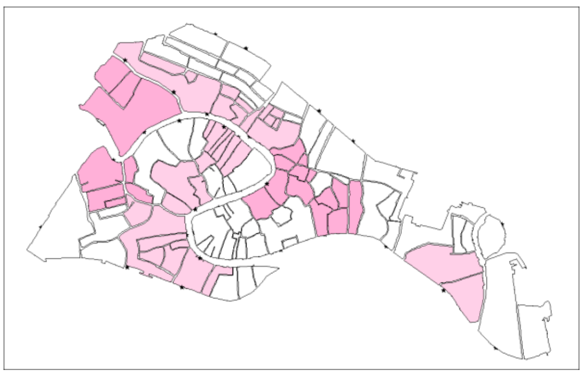


Figure 31 – Pedestrian Dispersion from Boat Stops (2 AM — 3 AM)

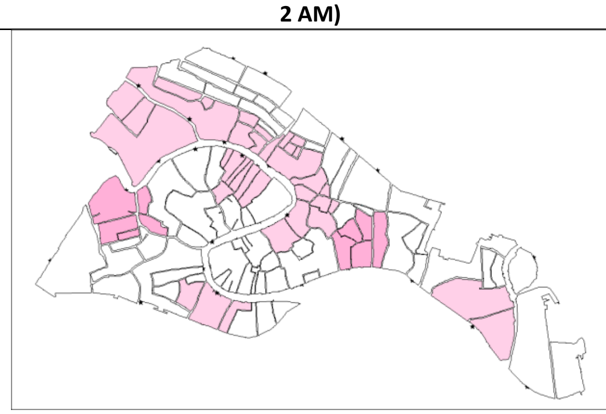


Figure 32 – Pedestrian Dispersion from Boat Stops (3 AM — 4 AM)

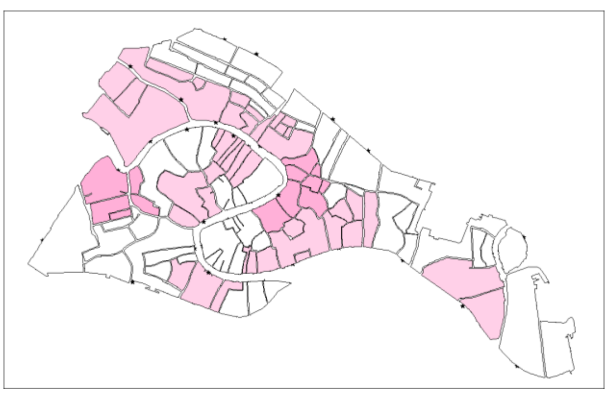


Figure 33 – Pedestrian Dispersion from Boat Stops (4 AM — 5 AM)

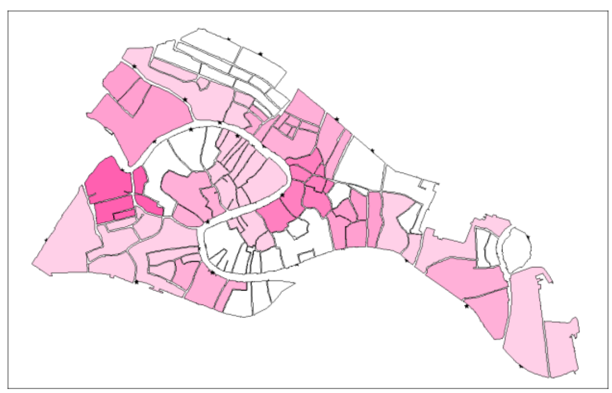


Figure 34 – Pedestrian Dispersion from Boat Stops (5 AM — 6 AM)

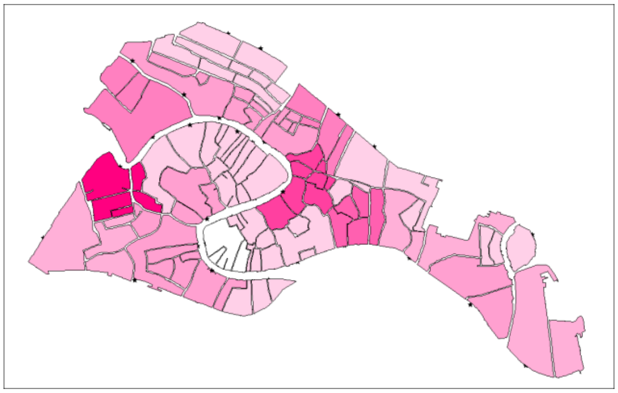


Figure 35 – Pedestrian Dispersion from Boat Stops (6 AM — 7 AM)

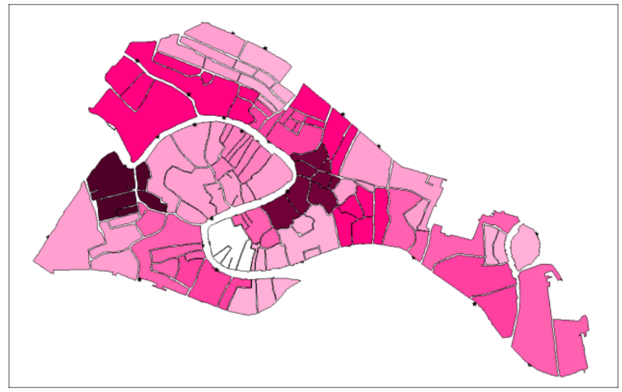


Figure 36 – Pedestrian Dispersion from Boat Stops (7 AM — 8 AM)

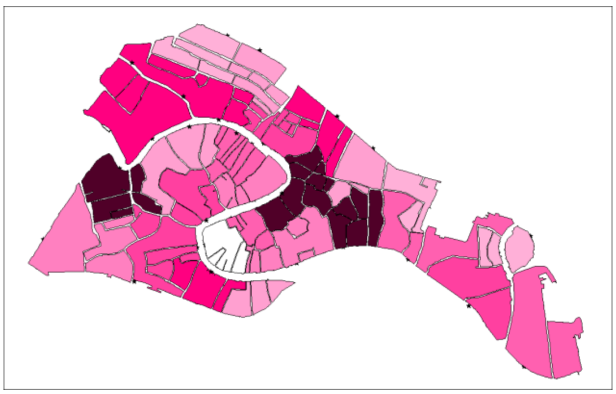


Figure 37 – Pedestrian Dispersion from Boat Stops (8 AM — 9 AM)

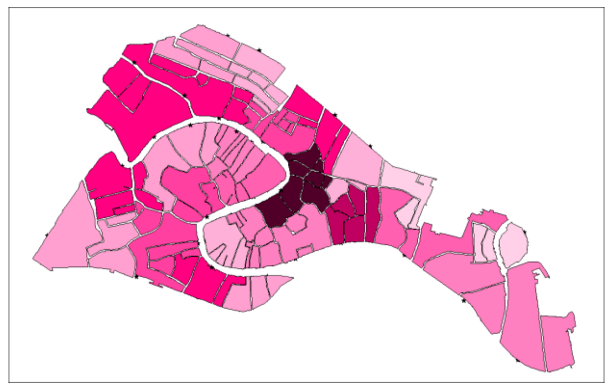


Figure 38 – Pedestrian Dispersion from Boat Stops (9 AM — 10 AM)

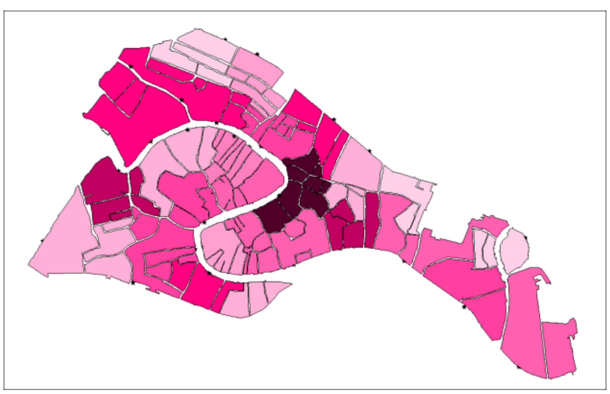


Figure 39 – Pedestrian Dispersion from Boat Stops (10 AM — 11 AM)

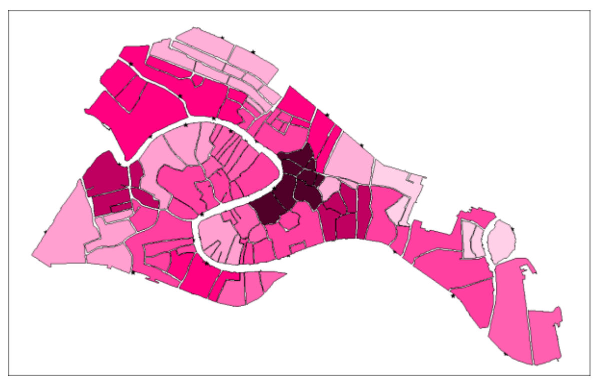


Figure 40 – Pedestrian Dispersion from Boat Stops (11 AM — 12 PM)

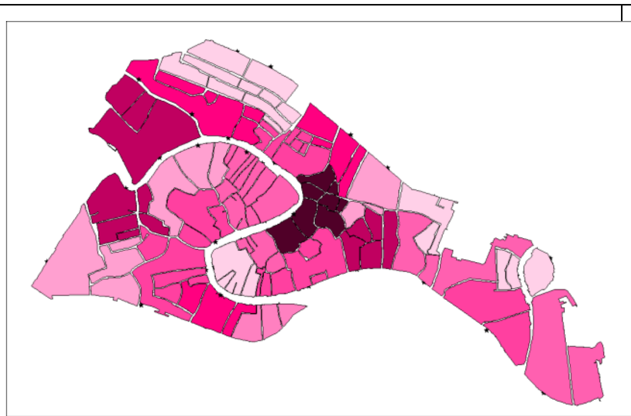
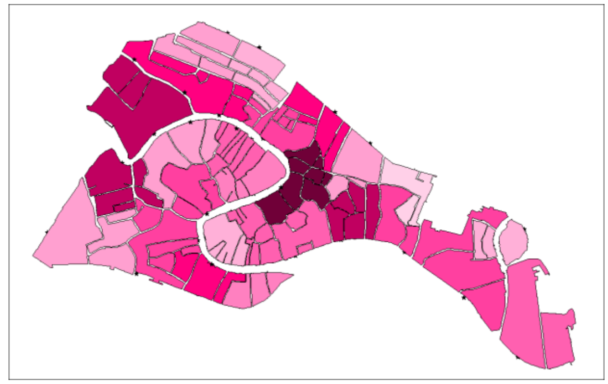
	

Figure 41 – Pedestrian Dispersion from Boat Stops (12 PM — 1 PM)	**Figure 42 – Pedestrian Dispersion from Boat Stops (1 PM — 2 PM)**

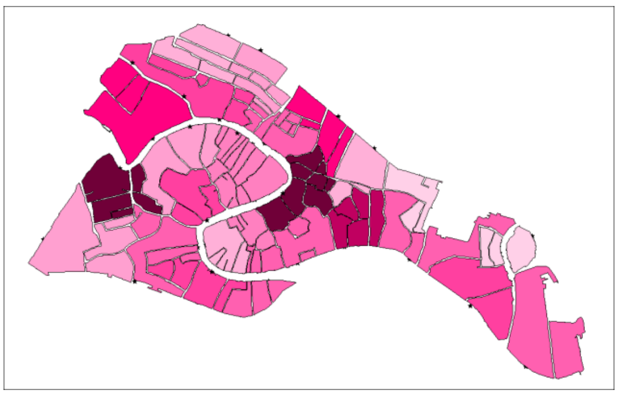
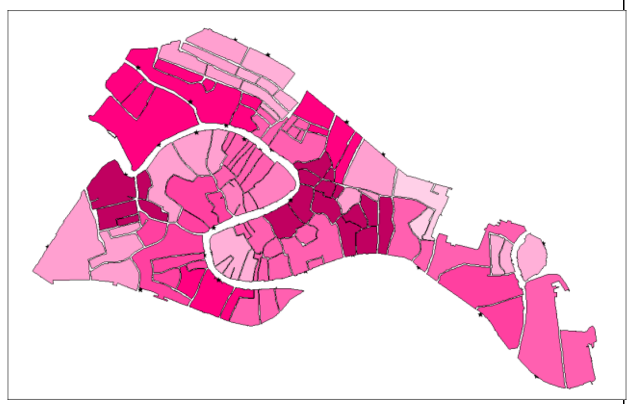

	

Figure 43 – Pedestrian Dispersion from Boat Stops (2 PM — 3 PM)	**Figure 44 – Pedestrian Dispersion from Boat Stops (3 PM — 4 PM)**

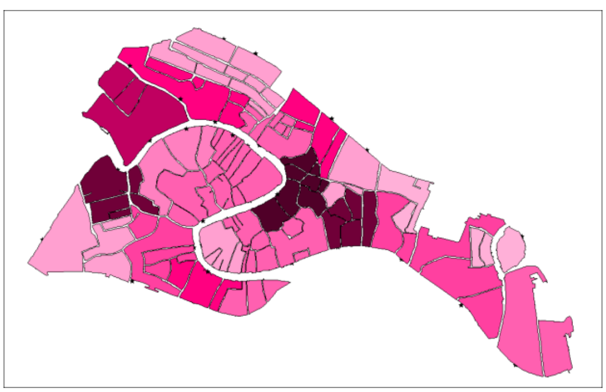
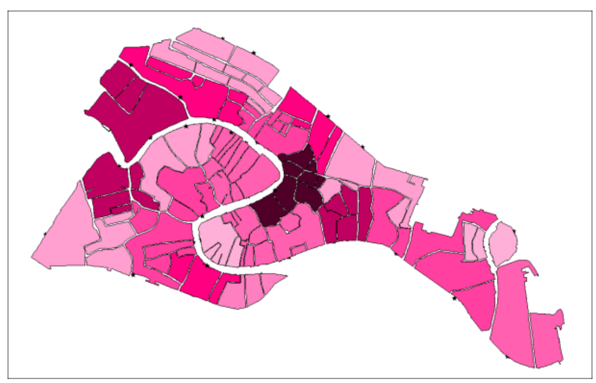

	

Figure 45 – Pedestrian Dispersion from Boat Stops (4 PM — 5 PM)	**Figure 46 – Pedestrian Dispersion from Boat Stops (5 PM — 6 PM)**

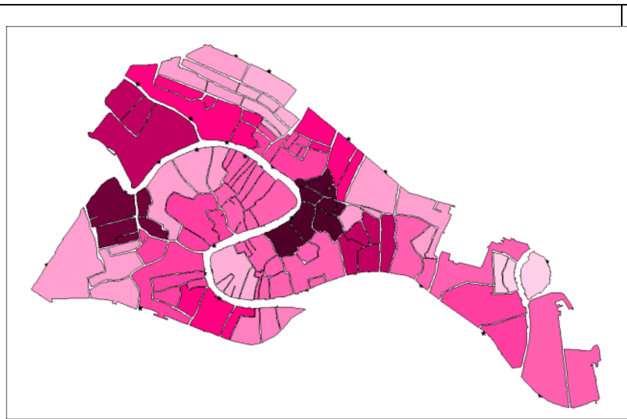
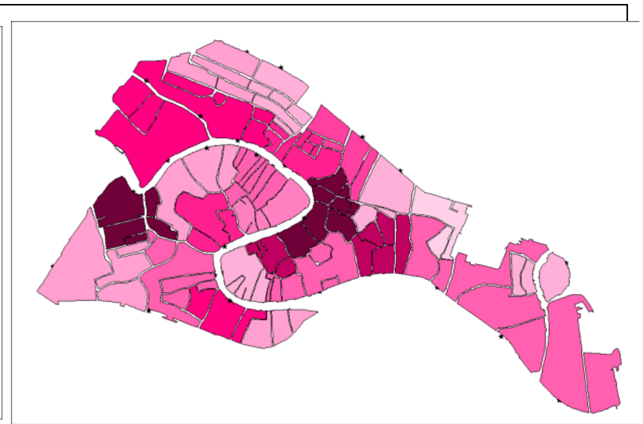
	

Figure 47 – Pedestrian Dispersion from Boat Stops (6 PM — 7 PM)	**Figure 48 – Pedestrian Dispersion from Boat Stops (7 PM — 8 PM)**

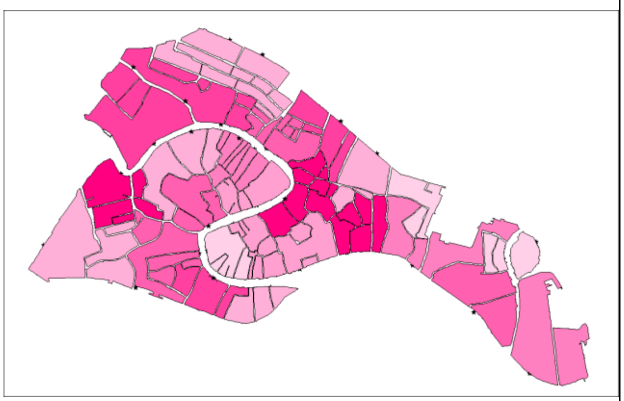
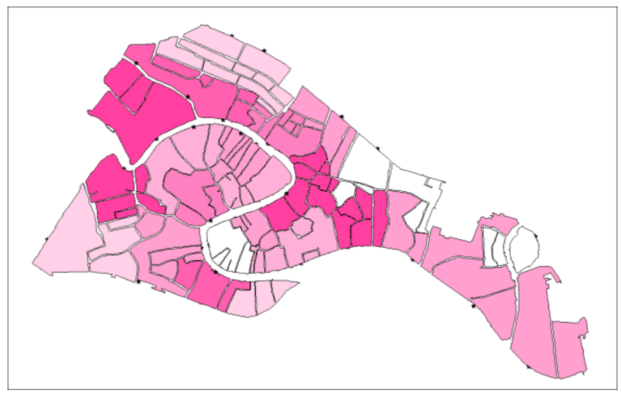

	

Figure 49 – Pedestrian Dispersion from Boat Stops (8 PM — 9 PM)	**Figure 50 – Pedestrian Dispersion from Boat Stops (9 PM — 10 PM)**

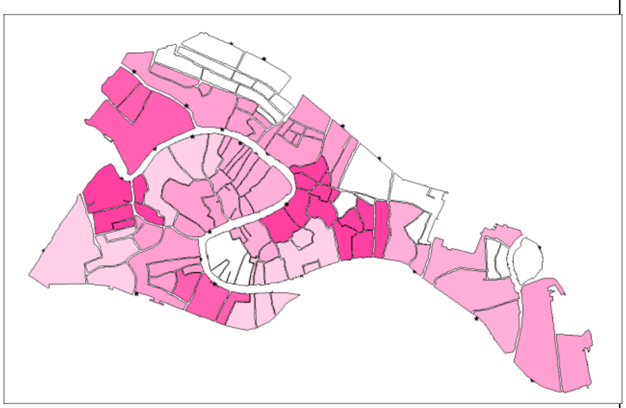
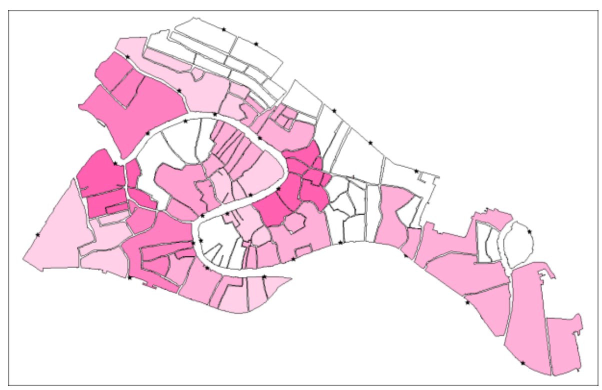

	

Figure 51 – Pedestrian Dispersion from Boat Stops (10 PM — 11 PM)	**Figure 52 – Pedestrian Dispersion from Boat Stops (11 PM — 12 AM)**

4.4 Analysis of ACTV Boat Data

It can safely be assumed that the majority of pedestrians who are utilizing the ACTV boats in their travels through Venice strive to get on a boat at the stop closest to their starting location, and get off the boat at the stop closest to their ending location. This will not always be true because of reasons such as a Venetian wanting to avoid traveling through an area that is heavily populated by tourists, a tourist accidentally getting off at the wrong stop, or a variety of other potential reasons, Such circumstances, however, make up a negligible percentage of the total boat use and can be ignored when developing a heuristic for the density of pedestrians who use boats throughout the city. A conglomerate boat catchment basin map was designed for this purpose. For the purpose of a holistic analysis, this map considers all of the boat stops without regard for which boat lines service which stops.

Inspection of the maps yields several interesting observations. The catchment basin servicing *Ponte de Rialto* experiences a large spike in traffic between 7:00 AM and 8:00 AM, which can be attributed to the stores along Rialto opening at approximately this time. There is a small but noticeable drop in the traffic surrounding Ponte de Rialto between 1 PM and 4 PM, which corresponds with the time that many of the shops close for lunch. Traffic trails off for the night beginning at 8 PM when the shops begin to close.

Central Venice consistently has less traffic that the areas immediately surrounding it on all sides. This can be attributed this area being primarily utilized by Venetians, who are more likely to walk as a primary means of transportation and less likely to use the ACTV boat lines. The majority of the people traveling in this area will not be captured by an analysis of boat riders.

The catchment basins servicing *Piazzale Roma* and *Ferrovia* approximately follow the daily train schedule. This indicates that the majority of people traveling to and from these places tend to travel by boat. This is likely due to pedestrians traveling to and from the train and bus stations with suitcases (especially considering the difficulty of walking through Venice with a suitcase).

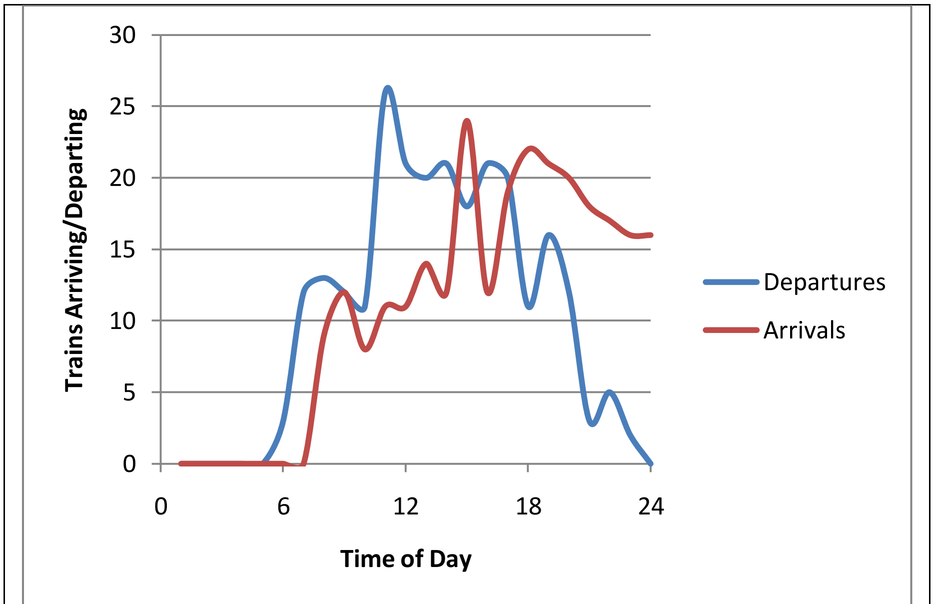


Figure 53 – Passenger Trains Arriving and Departing from Venice Train Station

The catchment basin servicing San Marco is consistently less heavily traffic than the neighboring catchment basin associated with the *San Zaccaria* boat stop. It is counterintuitive to see *San Marco*, one of the most heavily trafficked areas of Venice (and possessing its own boat stop), supporting so little pedestrian traffic originating from ACTV boats. This suggests that while many guidebooks insist that the best way to approach San Marco is via water, most pedestrians do not heed this advice. Rather, they are opting to travel across *Ponte della Paglia* in order to view the Bridge of Sighs.

4.5 Boat Traffic Recommendations

Gondole are one option that has not been explored at this point. *Traghetto* crossings across the Grand Canal feed mostly local traffic, and tourist sightseeing gondola trips can influence that demographic. Water taxis are another possible area for study. Studying the *Alilaguna* water-busses would also provide interesting data as the traffic from the airport and beyond is another set of pedestrian source data which has yet to be explored.

5 Evacuation Case Studies

There are many areas of Venice that are particularly prone to less than ideal emergency evacuations. One of the objectives of this project is to analyze and model some of these areas in hopes that by having more information about what is likely to happen during an emergency evacuation, city officials will be able to design better protocols for dealing with such situations. The main task involved in such an analysis is to study the areas under their peak conditions in order to best understand the starting points for all of the imaginable worst case scenarios.

5.1 San Marco

Saint Mark's Square, or *Piazza San Marco*, is the most recognizable and visited area in the city of Venice. The iconic location is home to Saint Mark's Basilica, the opulent and gilded epitome of Venetian religious architecture, the world-famous flocks of pigeons, and an almost continuous stream of tourists. These tourists are the reason that this square is so important; most, if not all tourists to the city will visit the *Piazza* at least once during their stay, making it a crowded and integral part of the pedestrian model fed by so many individuals that do not live in Venice.

5.1.1 San Marco Background

In the past, an evacuation model of this square has been created to simulate what would happen in the event of an emergency. This model shows people running away due to something like a bomb scare. The main issue within this model is that tourists do not exhibit what could necessarily be realistic behavior. The behavior that these agents exhibit makes them run towards one of about four or five exits. In reality, there are many more possible ways to exit the square, and it is unlikely that, in the event of a disaster or scare, people in real life would act like this and clump together into such large, slow groups.

Figure 54 – Previous evacuation model of Piazza San Marco

5.1.2 Methodology for Quantifying Pedestrians in St. Mark's Square

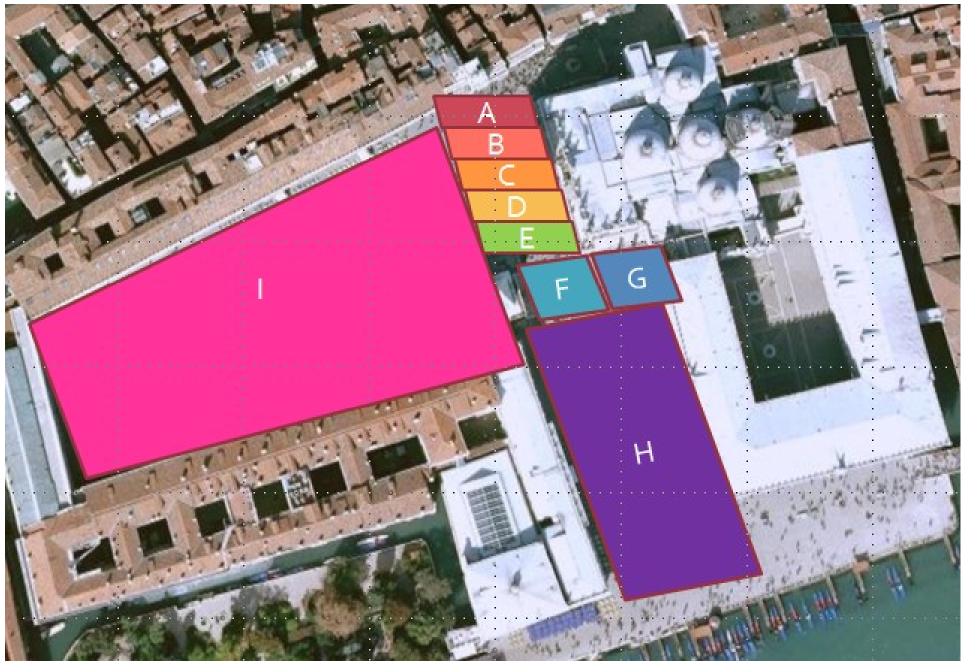


Figure 55 – Analysis regions in the *Piazza San Marco*

Several methods were used to describe movements of pedestrians traveling through the *Piazza San Marco*. First, aerial photographs were taken from the top of the *San Marco* bell tower, and from the balcony on St. Mark's Basilica. These vantage points provided a full view of the square, better than from any other locations. These photos were taken at regular intervals, to show the change in the demographics within the square. Pedestrians in each of these pictures were manually counted and recorded in a spreadsheet (found in the appendix). Also, short videos were taken from these locations, to show the average flow of people in the square.

Figure 56 – Pedestrian Counting Picture taken from the Bell Tower in St. Mark's Square

Figure 57 – Pedestrian Counting Picture taken from the Balcony of the Basilica in St. Mark's Square

In addition to these methods, specially chosen individuals were followed throughout the square with a GPS receiver, leaving electronic "breadcrumbs" to show the path each person walked through the square. Fifteen people were followed in this way, twelve of whom were tourists. This ratio is skewed because there are many more tourists in the square, because of their abundance, and also because of the apparent randomness of their paths. These GPS tracks were then exported from the GPS (via USB), and overlaid as moving time-dependent paths onto a Google Earth base map. An analysis of this GPS track data is discussed in the *Results and Analysis* section of this report.

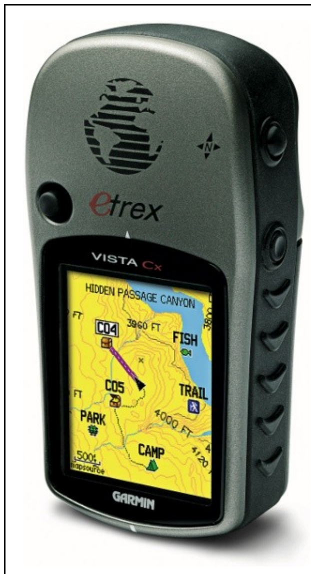


Figure 58 - Garmin eTrex Vista-Cx Used to Collect GPS Tracks in St. Mark's Square

5.1.3 Methodology for Qualifying Pedestrian Flow in St. Mark's Square

Pedestrians were also observed for qualitative trends in St. Mark's Square. The highly crowded areas were noted, and monitored for trends. Times of tourist ebbs and flows were also observed. These observations were made both in person and through analysis of the videos.

5.1.4 Piazza San Marco Traffic Results

As expected, the total number of pedestrians varies throughout the day, but it follows the same general trend as pedestrian volume flow across the Category 1 bridges in Venice (as seen in the analysis below).

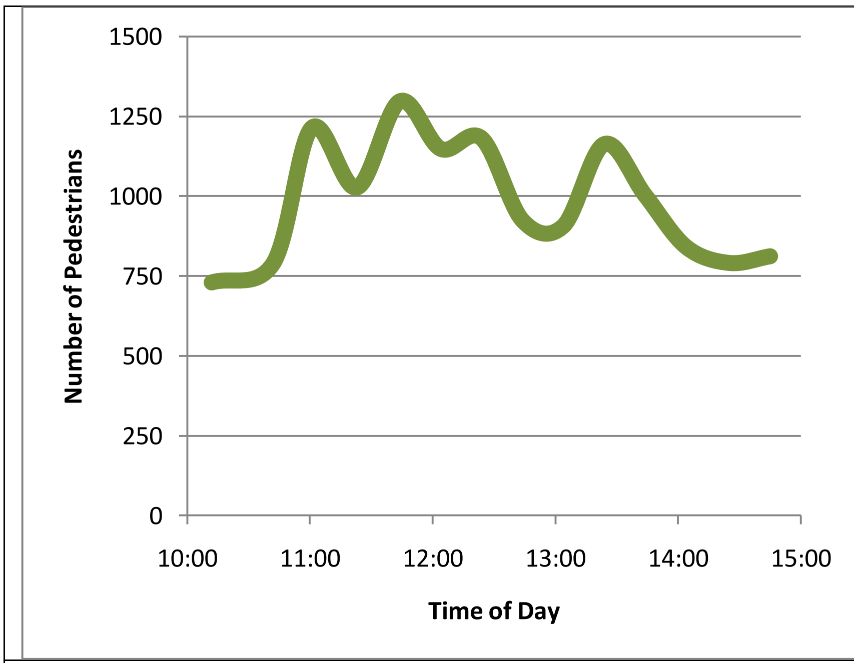


Figure 59 – Number of people in St. Mark's Square on a Weekend Day

Because the *Piazza San* Marco is such a well known tourist destination, most Venetians tend to avoid traveling though the *piazza*. The pedestrian analysis, therefore, is impacted very little by the mobility habits of Venetians – St. Mark's Square is as close to a "pure sample" of tourist traffic as Venice has to offer.

An increase in traffic is seen as tourists leave their hotels for the morning, and the traffic steadily increased (despite some major perturbations) through midday. As with all traffic throughout the city, there is a slight dip in volume in the early afternoon when shops and restaurants close. Traffic increases again as the shops reopen in mid-afternoon and pedestrian volume decreases through the end of the day.

5.1.5 Piazza San Marco Traffic Analysis

Equally as important as the numerical traffic results are qualitative observations of their movements and reactions in public places. As expected, tourists tended to conglomerate near the entrances and exits of attractors in the square, specifically the bell tower and basilica. These line-like formations served only to congest traffic and make mobility in the square even more difficult.

Also of note are the paths taken by tourists and Venetians as they transit through St. Mark's Square. As mentioned above in Methodology, GPS tracks of Venetians and tourists were recorded in St. Mark's Square. As was expected, Venetians tend to take the fastest route through the square (although sometimes not the most direct, they tend to avoid the aforementioned conglomerations of tourists), while tourists walk in inefficient paths that cross back over each other and often traverse through the most congested areas of the square.

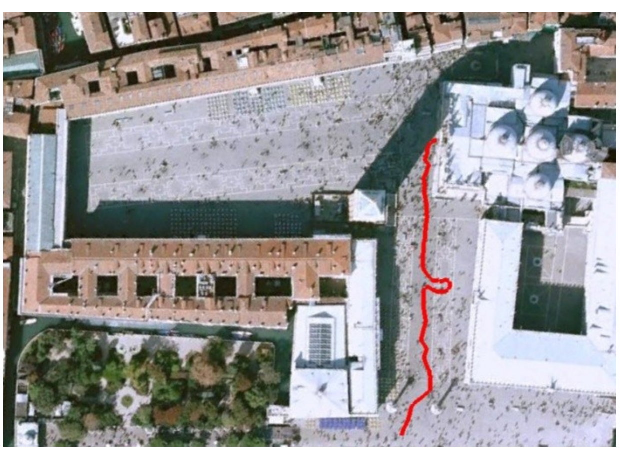


Figure 60 – Sample Path of a Tourist through St. Mark's Square

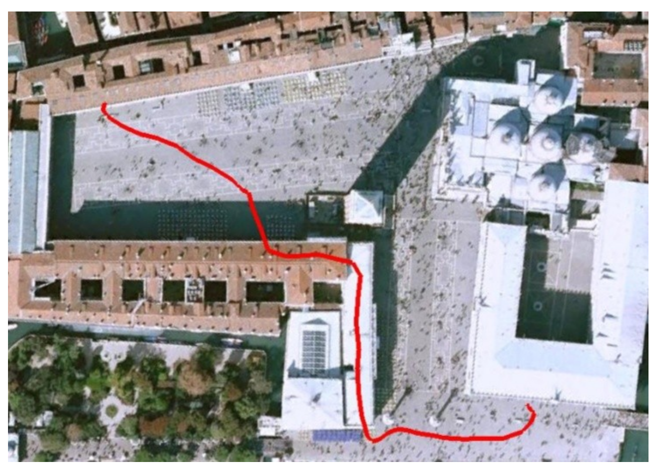


Figure 61 – Sample Path of a Venetian through St. Mark's Square

5.1.6 Piazza San Marco Recommendations

The analysis of pedestrians in St. Mark's Square used more data collection techniques than any other event or location studied, allowing ample room for improvement in future studies. The largest area for improvement deals with the electronic equipment used to survey pedestrians. Because this study received no funding from any source, only equipment already owed by the members of the project group was used (point-and-shoot digital cameras, GPS receivers designed for hiking, etc.). Using equipment such as time-lapse cameras and GPS tracking dongles would greatly improve the ease and accuracy of the counting process, and would increase the credibility of the methodology if it were to be applied to future studies.

In addition to task-specific equipment, the data analysis process could be much improved with the use of an automated system to count the number of pedestrians in each video and photo frame. Such a method would also drastically improve the efficiency of the data analysis process.

5.2 Festa della Madonna della Salute

On November 21st, the *Festa della Salute* is held, during which the square in front of the *Chiesa della Santa Maria della Salute* fills up with Venetians and tourists. The island with this church is located on the south-eastern corner of the Grand Canal, and is accessible on that date by a temporary bridge across to Grand Canal connected to the island on its west. The drastic increase in the number of people in this square makes it a valuable place to model and to describe how an evacuation would (and should) occur. Two narrow bridges and two boat stops are severe choke points for evacuating the island if an emergency were to arise.

5.2.1 Festa della Madonna della Salute Background

Both the Santa Maria della Salute church and the Festa della Madonna della Salute stem from the plague outbreak of 1629. To stem the tide of the plague, the Venetian Senate prayed to the Virgin Mary and ordered the construction of the Santa Madonna della Salute. In addition to the creation of the new church, the Senate mandated that the Feast of the Presentation of the Virgin, occurring every

November 21st, be celebrated at the new church. Since that time, the tradition has been upheld, with Venetian residents and officials making the pilgrimage to pay respect.

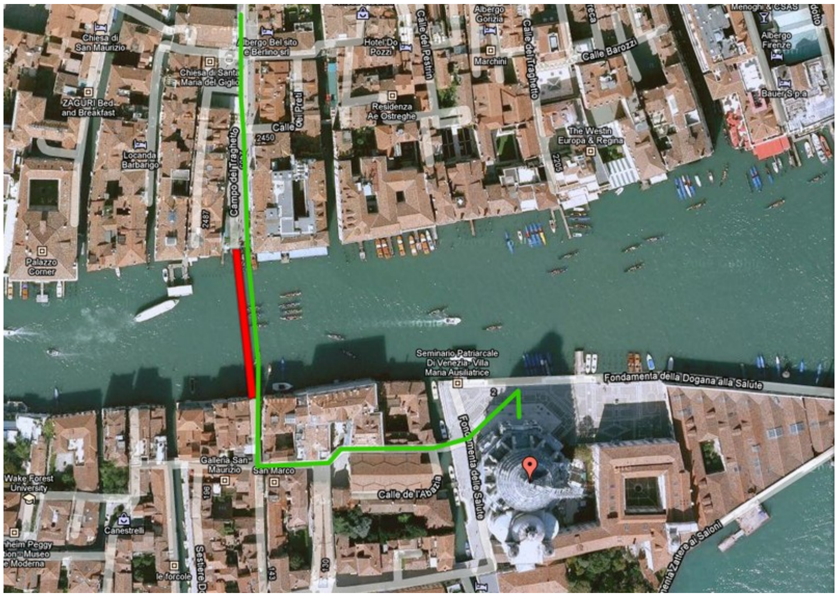


Figure 62 - Salute Procession Map

Today, the Festa della Madonna della Salute is one of the main religious and civic festivals in Venice. To support the event, a temporary pontoon bridge is constructed across the Grand Canal and Vaporetto traffic is redirected to accommodate the large number of tourists and Venetians who visit the Santa Maria della Salute during the the day.

Figure 63 – Salute Church

Figure 64 – Photo of crowd at the Salute festival

5.2.2 Methodology for Festa della Madonna della Salute

To create an estimation of the number of people in the square, five locations were chosen for pedestrian counting. From 7 AM to 10 PM, counts were taken at the northern bridge on the east side of the church, the bridge directly to the west of the church, the temporary bridge (erected specifically for this festival), and the two boat stops on the island itself. Mechanical counters were used to quantify the number of pedestrians that crossed at each point.

Figure 65 – Salute Island with the locations of the three bridges and two boat stops

The three bridges were counted in fifteen minute cycles, of which ten minutes were spent counting, and five minutes recording the data and relocating the next bridge. These intervals were repeated throughout the day. The two bridges directly on Salute Island were only counted for half of the time due to a lack of manpower, but the counts taken were sufficient to calculate an accurate approximation of the number of people traveling onto and off of the island. The temporary bridge had complete data collected for the entire day. When analyzing the data, counts were extrapolated to cover "holes" in the collected data resulting from counters taking breaks throughout the day.

In addition to the three bridges, there were two boat stops that had to be quantified. One person was stationed at each of the stops, and from 7 AM to 10 PM, they counted the number of people that entered and exited the stops with mechanical counters, and recorded the times of each. This was done continuously throughout the day, to populate the model accurately.

To compliment the counting that was completed at the Salute festival, a time lapse camera system was set up to take pictures once every sixty seconds from around 7 AM to 5 PM. The system consisted of a *Sony PS3eye* webcam connected via USB to a netbook. The camera was mounted on a telescoping tripod approximately 4 meters above the ground, and the tripod was attached to a railing at the eastern boat stop. The camera was angled such that it could capture most of the square and the doors to the church, to demonstrate the staggering number of people entering the church throughout the day. The limitation of this system was the battery life of the netbook – approximately 8 hours of time-lapse footage was recorded (enough to capture the peaks of traffic at the festival) before the batteries were exhausted.

5.2.3 Results from La Festa della Madonna della Salute

During the festival day, tens of thousands of people walked across the two bridges leading to the island. Figure 66 shows the monumental number of people that populated this square on the day of the festival. Collected data indicate that at one point during the festival, there were over 6,000 people at the Salute church and surrounding plaza: an incredible number of people for such a small area of land. There are two characteristic peaks in this graph, showing a midday rush and an afternoon rush. The dip in the number of people on the island can be attributed to the lunch rush. This graph shows not only the flow of traffic on the island, but also the total number of people on the island at any one time.

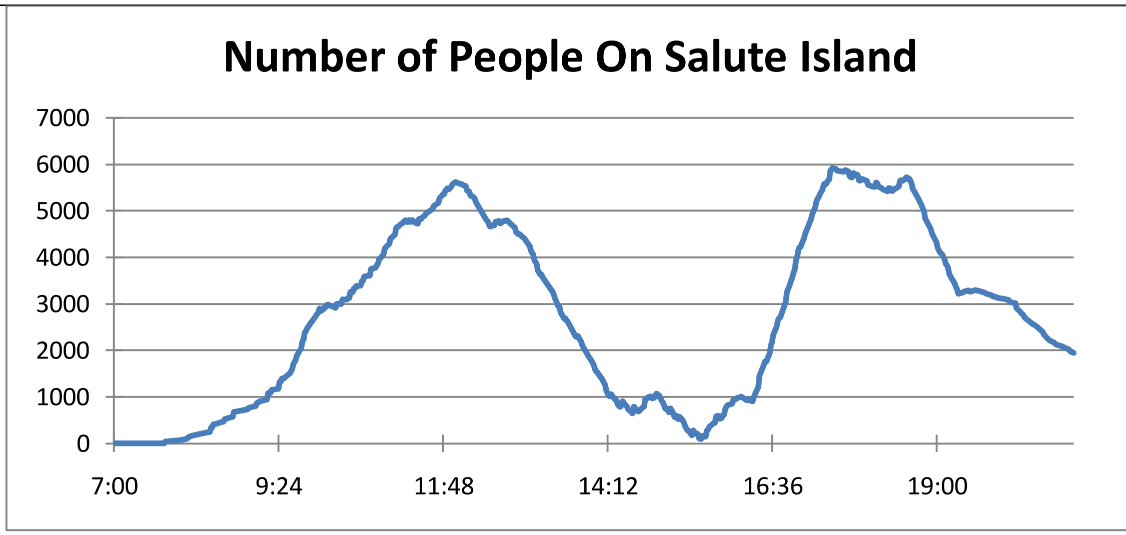


Figure 66 – Number of people on Salute island on *La Festa della Salute*

This large amount of people in a topographically diverse area provides the perfect location for an evacuation simulation. In the case of an emergency, actions that people will take are likely to be diverse and complex, making this the epitome of the evacuation application of the autonomous agent-based model. People would have the option to run towards bridges (which would quickly become congested). At that point, their options would be limited to pushing through the crowd and risking being trampled, or diving into the water and trying to swim to safety. This evacuation scenario has the ability to help a great number of people in case an emergency were to arise. *La Festa della Madonna della Salute* is one of the busiest events in the city of Venice. The people at this event fill the streets and squares around the church to the point where moving becomes difficult. Its unique location and diverse history also allow it to be a great example of how an evacuation model should work, while making its study interesting and relevant. At its peak, the festival drew over 200 pedestrians per minute (2000+ per 10-minute counting period), and well over 100,000 pedestrians passed across the island on the festival day (nearly double the population of Historical Venice).

5.2.4 Analysis of Fests della Madonna della Salute

The data above show two clear surges in pedestrians: midday (as workers are released for their lunch break), and after businesses close for the evening (as workers go home for the evening). Although many tourists attended the event, the data appear to strongly follow trends associated with the native working population of Venice.

The pedestrian traffic flow was severely constrained and artificially routed by police presence on the day of the festival, including the institution of one-way bridges, restricted areas on the island, and designated entry and exit points at the church. These restrictions produced an artificial, but still measurable, flow of pedestrians.

As seen in the time-lapse video of the festival, pedestrians tended to “funnel” across bridges and into the doors of the church. Although these two choke points (bridges and church entries) caused the most noticeable backup of pedestrians, the large open plaza surrounding the church was also extremely crowded and the sheer volume and density of pedestrians in this area caused even more substantial backups around the church and boat stops.

Figure 67 – Sample of time lapse photos from the Salute Festival

5.2.5 Festa della Madonna della Salute Recommendations

One improvement to this study that could be easily implemented in the future would be to use an actual time lapse camera, as opposed to the set-up that was used for this project. The increased battery life afforded by such a camera would allow for a time lapse of the entire day to be captured. Additionally, a shorter interval should be used between pictures; perhaps something around 30 seconds would be more appropriate and produce a smother video. Setting up a second time laps covering the carnival area would also be likely to yield interesting results.

This study looked exclusively at the area outside of the church. It would be extremely valuable to examine the traffic flow within the church. If an emergency were to occur, getting people safely out of the church would probably be a higher concern than getting people off of the island; knowledge pertaining to how the people within the church are moving would allow for a much more useful analysis.

5.3 San Michele Cemetery

Figure 68 – San Michele Cemetery

San Michele Cemetery was chosen as a case study because of the high potential for disaster in an emergency evacuation scenario. On one day a year, the island receives far more traffic than normal and if an evacuation were to be necessary on that day, the available transportation resources would most likely prove to be inadequate.

San Michele Cemetery Background

On November 2nd, All Souls Day, many Venetians take the free boat to the Island of San Michele. This island is the Venetian cemetery, and these individuals go to pay their respects to deceased family members. If an emergency evacuation were to become necessary, this island and day provide a unique challenge to emergency workers. The island of San Michele is only accessible by boat. Several *vaporetti* are appropriated to transport people to and from San Michele on All Souls Day.

5.3.1 Methodology for San Michele Cemetery

To measure the number of pedestrians on the island, counts were taken as boats arrived at the two boat stops on the island. For each boat, the number of pedestrians entering and leaving the island was recorded, along with the boat number, direction, and time. This data was collected through physical observation using mechanical “clickers” at each boat stop point on All Souls Day, for the span of several hours.

5.3.2 San Michele Cemetery Recommendations

The weather on November 2^{nd}, 2009 was very inconducive both to analyzing traffic and more importantly to people who would have otherwise visited San Michele on that day. The weather conditions rendered any data gathered on this day irrelevant and unusable. This study would highly benefit from being repeated under more typical conditions for that day.

6 Computer Model of Venetian Traffic Patterns

The collected and analyzed data above is a worthy academic and mathematical exercise in data collection and statistical analysis, but has no real benefit to any Venetians. The collected data can be integrated into a synthesis that allows interactive simulations of pedestrian movement in Venice– an invaluable tool for city planners and other corporate and government officials. A graph-theoretical model was used to program the autonomous agent model, as described below.

The final objective of this project was to develop a preliminary model of overall Venetian traffic flow and to design a theoretical framework from which an all-encompassing model can be developed in the future. The primary tasks associated with doing this were to identify the information which would be valuable as inputs to the model, develop a methodology for using said information, and to design an environment in which the results of the model can be displayed.

6.1 Modeling Background

In the past, there has been a large amount of work done to model pedestrians for various systems. For the many applications, such as urban planning and construction of high pedestrian density buildings (such as rail stations), there are naturally many forms that pedestrian modeling can take. To accommodate this broad requirement, a number of programs have been created to assist with urban planning through computer modeling.[22] Rarely though, has modeling been used to describe pedestrian movement throughout an entire city. While many programs exist for modeling pedestrians inside single buildings (or similar sized locations), larger scale programs for city-sized modeling are not common in this field. Instead, a more specialized system had to be developed for this Venetian mobility project. The concepts behind pedestrian modeling are relatively simple: a set number of agents moving around at a specified time, governed by a set of rules defining how and when they can move (a set of constraints that is critical to the human-like operation of the model's autonomous agents).

[22] (Harney 2002)

Figure 69 – The "*SimTable*" Boat Model

These agents can move around within a set boundary; in the case of a city, these boundaries are the streets and walkways. This general technology is fairly common when urban planners and civil engineers want to describe how traffic will move in an area. One example in particular is the *SimTable*-based boat model of Venice, produced by the Redfish group[23]. This model is an accurate representation of the way that boats can move around the city, though it lacks intelligence. For example, when a boat in the model comes to an intersection, it can only go down one of the paths that exist. In this way, the mechanics of the model are solid; as the boats do not deviate off of their specified paths. The main problem with this system is the randomness of path selection: when forced to make a choice, the boats have an equal likelihood of choosing any possible path, including going backwards along the path that led them to the intersection. This model is not based on any real data, but is rather a proof-of-concept of a model displaying the paths a boat can take, not those that it is likely to take. As a foundation, this model serves its purpose, but its mechanics need improvements in order to model realistic behavior.

The original *SimTable* model was written in the *Panda3D* programming language because of the need for detailed graphics. The model for this project was also developed in *Panda3D* for similar reasons. Autonomous agent models in theory can (and most likely have) been developed in almost every high-level programming language.

While we were not the first group to model agents intelligently, nor the first to model traffic Venice, we are the first to start creation of a comprehensive and interactive model of the city of Venice.

[23] (Redfish Group 2009)

6.2 Modeling Methodology

The main goal of our project was to characterize and analyze the flow of pedestrians in the city of Venice, model that information in a graphically accessible format, and use the data for emergency-preparedness and city planning applications. These objectives require four distinct data sets: detailed census data and maps of the city, information on pedestrian flows across bridges throughout the city, pedestrian flow data from high-traffic events and locations in Venice, and usage statistics for the public boat transit system. These requirements necessitated the development of a high-fidelity methodology for counting pedestrians in several situations.

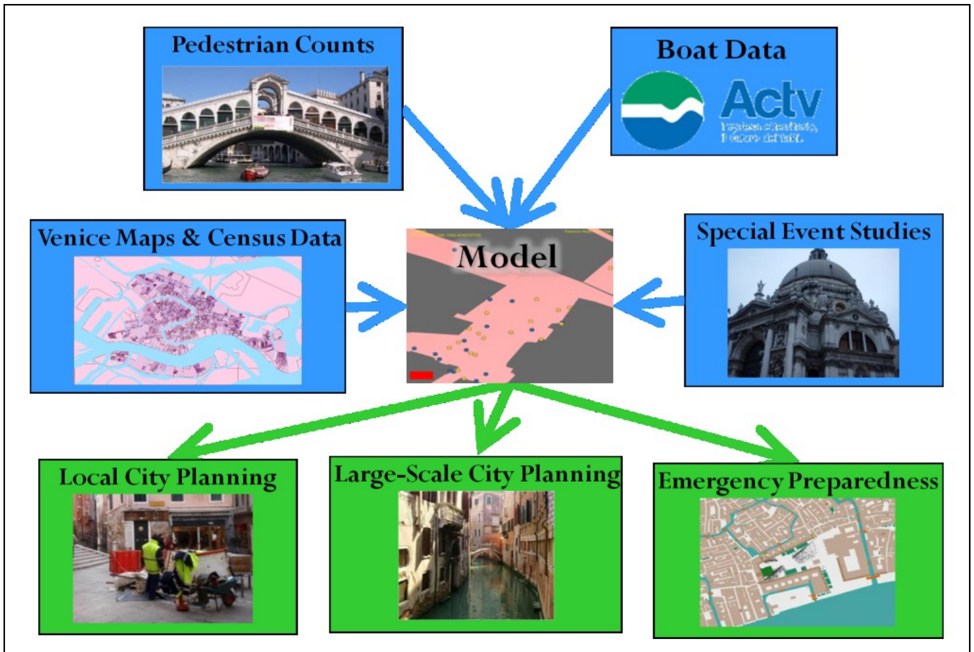


Figure 70 - Proposed Mobility Model

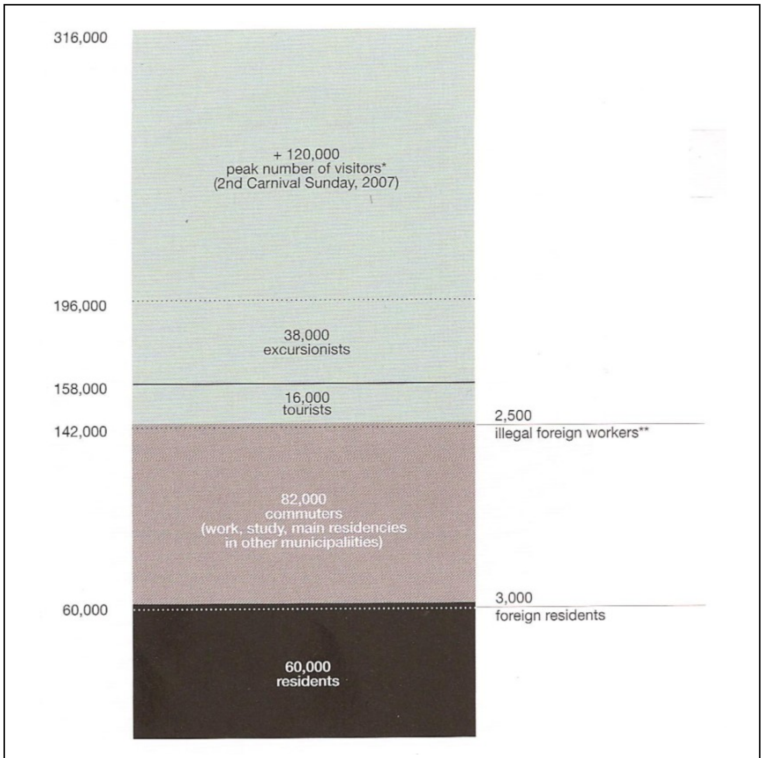
Maps and census data were taken from archives that already existed at the Venice Project Center from studies in previous years. Pedestrian bridge data was collected by physically counting pedestrians at 28 key bridges throughout the city. Data was also collected at several high-traffic locations: the Piazza San Marco on a typical weekend, the plaza surrounding *La Chiesa di Santa Maria della Salutee* on the church's feast day, and the *San Michele* cemetery on All Souls Day. In addition, usage data for the public transit system was solicited from the Venetian public transportation authority.

6.3 Theoretical Computer Model

Venice is a very unique area in that it is an exclusively pedestrian area and an archipelago. Consequently, the only options that people have for moving between islands are to cross a bridge or to utilize a boat. As both of these options create choke points and thus as a general heuristic, it was safe to assume that during any given traversal of Venice from an origin to a destination location, the pedestrian would attempt to minimize the number of islands that they must traverse. In order to mimic this real life action in our model while minimizing computational requirements, we viewed Venice as a graph and place people on islands throughout the day accordingly. To see how pedestrians move once they are on the streets, we considered a particular island, populated it with an agent for each pedestrian who is on that island at that point in time, and then allowed the agents traverse the island intelligently.

6.3.1 Initial Locations of Autonomous Agents

The initial location of agents representing Venetians was based on census population data from 2001 citation. Since Venetians of different ages were known to have very different movement patterns, the population census data was broken up into the following subdivisions. Children aged 0 to 4 were ignored because they would almost never be found walking without being accompanied by a parent and even then, wouldn't be doing a large amount of moving throughout the city. The next group was children aged 5 to 9.



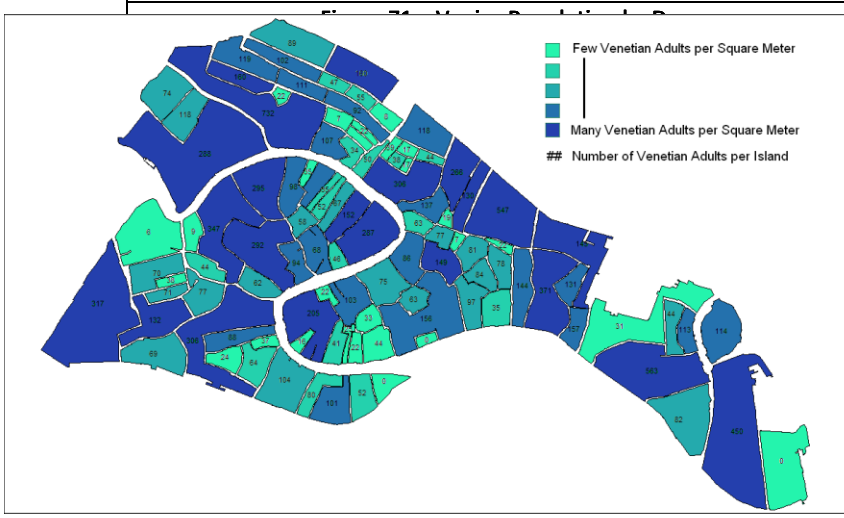


Figure 72 – Venetian Adults

The movement patterns of this group would likely be dominated by travel between home locations and elementary schools. People aged 10 through 19 were placed into a third category, as this group's movement patterns would be dominated by travel between home locations and secondary schools. The final group of Venetians was adults, whose movement patterns would be predominately determined by travel between home and work locations. The age divisions are known to not be ideal, but the 2001 census data was bracketed off into 5 year age groups, with no subdivisions within those groups and the aforementioned groupings of these age brackets were the best possible approximation for the desired age groupings. The following heat maps show the dispersion of people within these age groups throughout Venice.

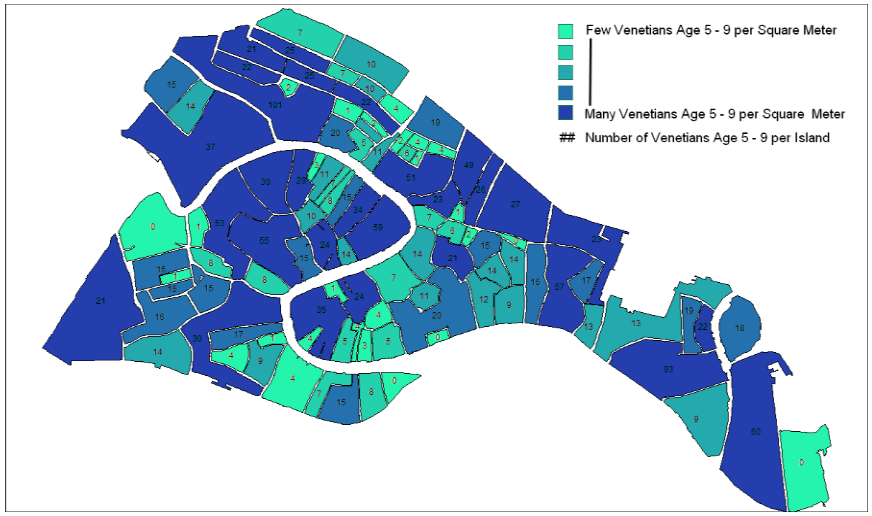


Figure 73 – Venetians Age 5 - 9

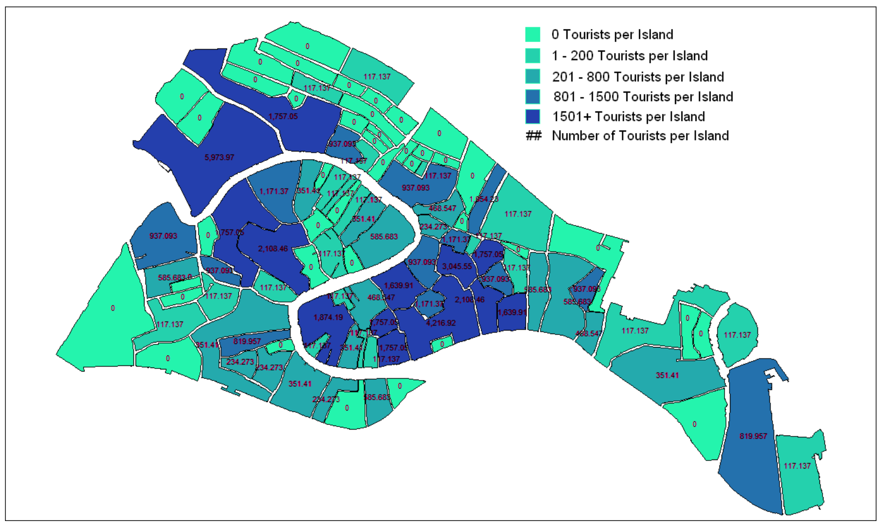


Figure 74 – Venetians Age 10 – 19

Tourists come in two varieties, traditional tourists who stay in Venice overnight, most commonly in a hotel, and excursionists who stay in Venice for only a single day. On a typical day in Venice, there are 16,000 traditional tourists and 38,000 excursionists. The initial locations for traditional tourists are mapped to the hotel locations while the initial locations for excursionists are mapped to the train and bus terminals.

The initial locations for traditional tourists were approximated by examining the locations of hotels throughout Venice, using the heuristic that on average, each hotel will have the same number of occupants. This is known to not be a completely accurate representation, but it can be assumed that the discrepancies will balance each other out when looking at the city as a whole. The following calculation was used to determine the approximate number of traditional tourists on each island.

$$\forall x | x \text{ is an island in Venice}$$

$$\# \text{ of tourists on } x = \frac{\# \text{ of hotels on } x}{\# \text{ of hotels in Venice}} * \# \text{ of traditional tourists in Venice}$$

The results of this calculation can be seen in the following heat map of Venice.

There are several ways in which excursionists can enter Venice, namely, by cruise ship, train, bus, or car. The initial location for excursionists who enter the city by train is *Ferrovia* and the initial location for excursionists who enter through all other means is *Piazzale Roma*. As documented in *Migropolis* (Scheppe 2009), approximately 8167,293 people arrive in Venice by bus on a typical day and 22,332,959 people arrive by cruise ship on a typical day. There is not data on the number of people who arrive every day by train and by car, but we have estimated those numbers to be 25,000 people by train per day and 2,600 people by car per day.

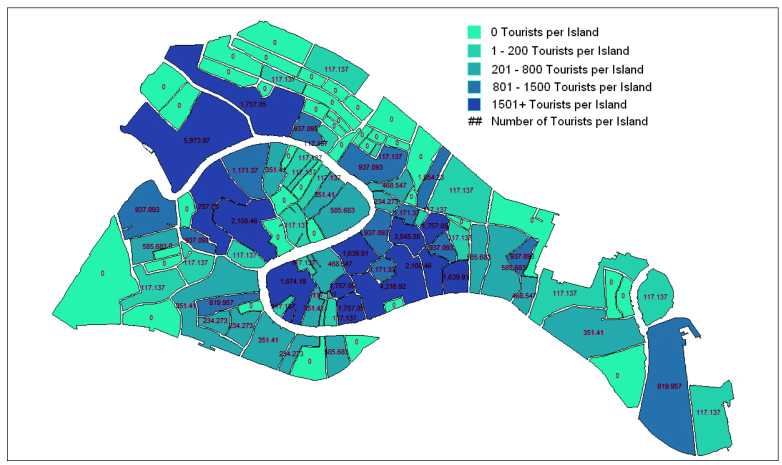


Figure 75 – Tourists in Venice (1 day)

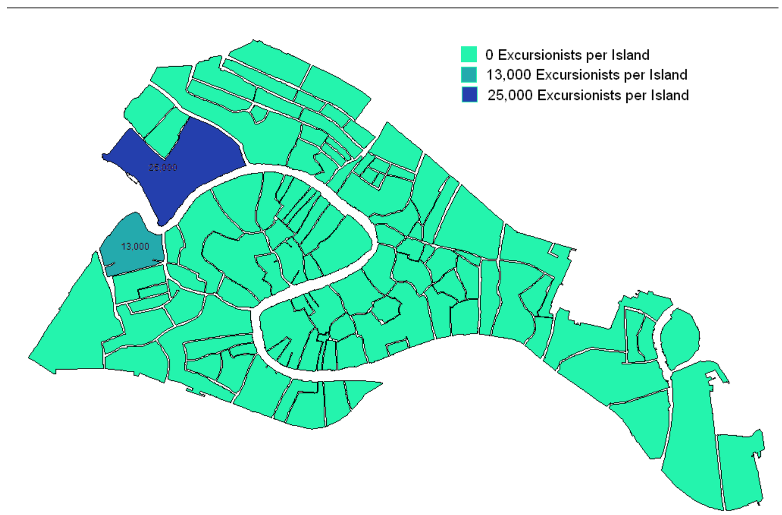


Figure 76 – Excursionists in Venice (1 day)

6.3.2 Points of Interest for Autonomous Agents

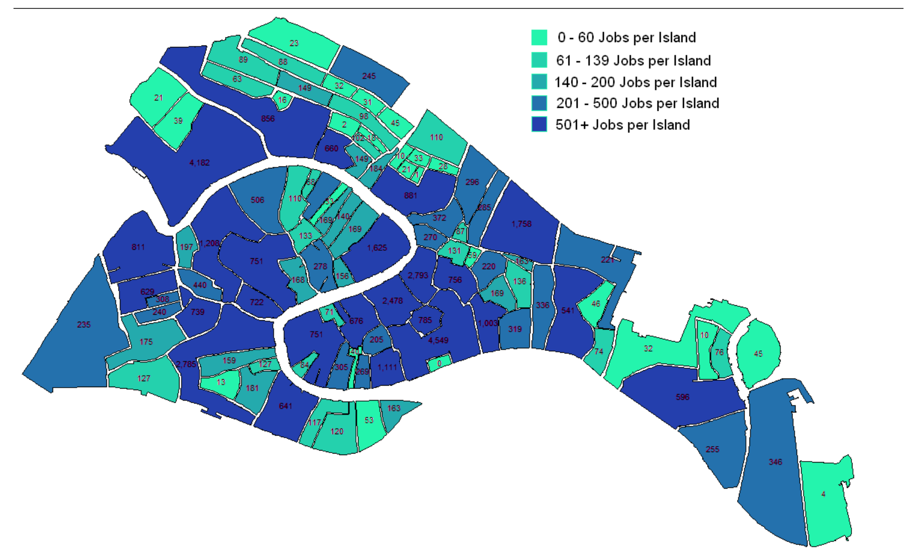


Figure 77 – Jobs by Island

As the pedestrians move throughout Venice, as when pedestrians move throughout any other area, they are traversing between various target destinations. There are two types of points of interest. The first and most common type is an indoor point of interest. When a pedestrian reaches an indoor point of interest, they will typically go inside the destination for some period of time, during which that person will no longer be contributing to the overall Venetian mobility. The second type of point of interest is an outdoor area. When a pedestrian reaches an outdoor area point of interest, they will spend a period of time moving throughout that area, but since they are still outside and other pedestrians may be using that same area merely as a means of traversal, pedestrians who are in outdoor points of interest continue to contribute to the overall Venetian mobility. The typical target destinations vary based on the type of person. For the purposes of this model, pedestrians were divided into tourists and Venetians.

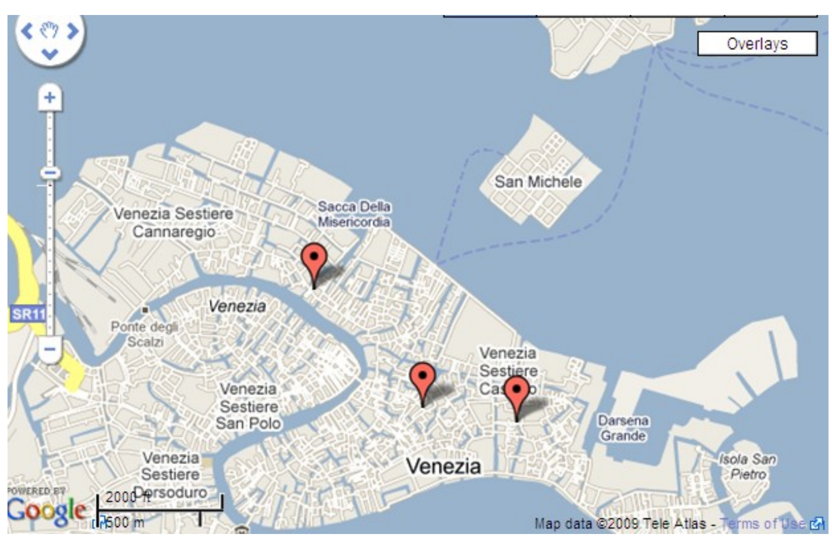


Figure 78 – Venetian Grocery Stores (from left to right: *Billa*, *Suve*, *Punto*)

The Venetian category is further subdivided into adults, young children, and older children and teen-agers. The most common points of interest for adults are work locations and grocery stores. Figure 77 displays the number of jobs on each of the Venetian islands. Each job is mapped to exactly one Venetian adult. As there are more Venetian adults than there are jobs, this is not a one-to-one mapping and consequently, there will be some Venetian adults who are not mapped to jobs. Due to the lack of available heuristics to increase the accuracy of the model as compared to the real world in the mapping of jobs to Venetian adults, a random mapping was used. Figure 78 depicts three of the main grocery stores that Venetian adults would be likely to visit at the end of a work day.

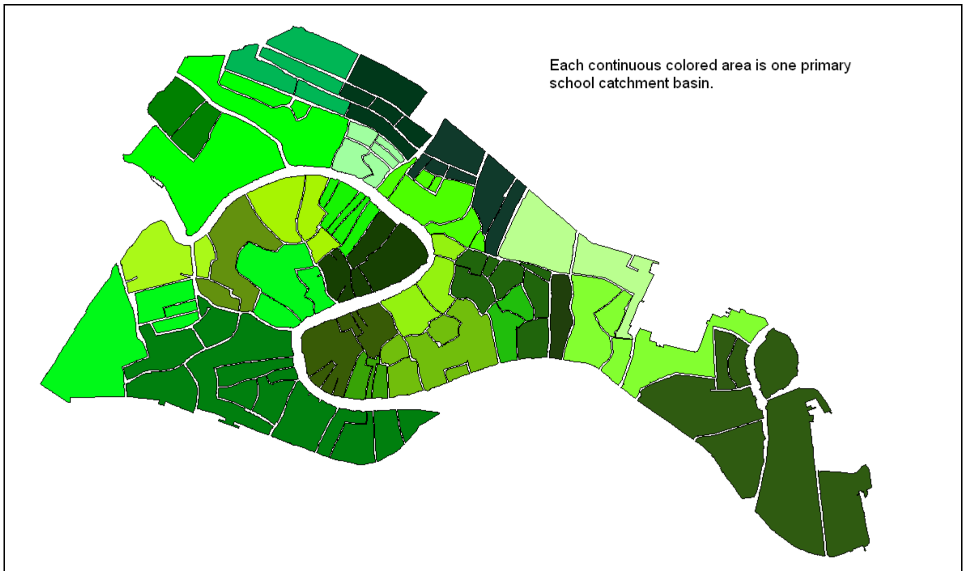


Figure 79 – Primary School catchment Basins by Island

The primary (and in many cases only) points of interest for Venetian children and teen-agers are schools. The data on the exact geographic regions that are serviced by each school has not been made publically available, but a general heuristic is that any given student is most likely to attend the school that is the shortest distance from their home. Since the placement of agents within the model is a two step process in which they are first placed on the appropriate island, and then subsequently on a path within that island, the schools are grouped by island, as shown in the maps in this section.

There are 23 islands in Venice with primary schools located on them. Figure 81 illustrates the regions where all primary school aged children who live within that region are most likely to be attending primary school on the same island based on the aforementioned heuristic. As there is a relatively large ratio of primary schools to islands, all of these regions are fairly small.

Venice contains nine islands with secondary schools located on them. Similarly to primary school aged children, secondary school aged students, namely older children and teenagers are most likely to attend the secondary school that is located the closest to their homes. Figure 80 illustrates the regions in which all secondary school aged children will most likely attend school on the same island. An interesting point of comparison between this map and the previous map is how much larger the regions are for the secondary schools. While this is not a particularly surprising fact, it undoubtedly has an impact on the traversal patterns of students of varying ages.

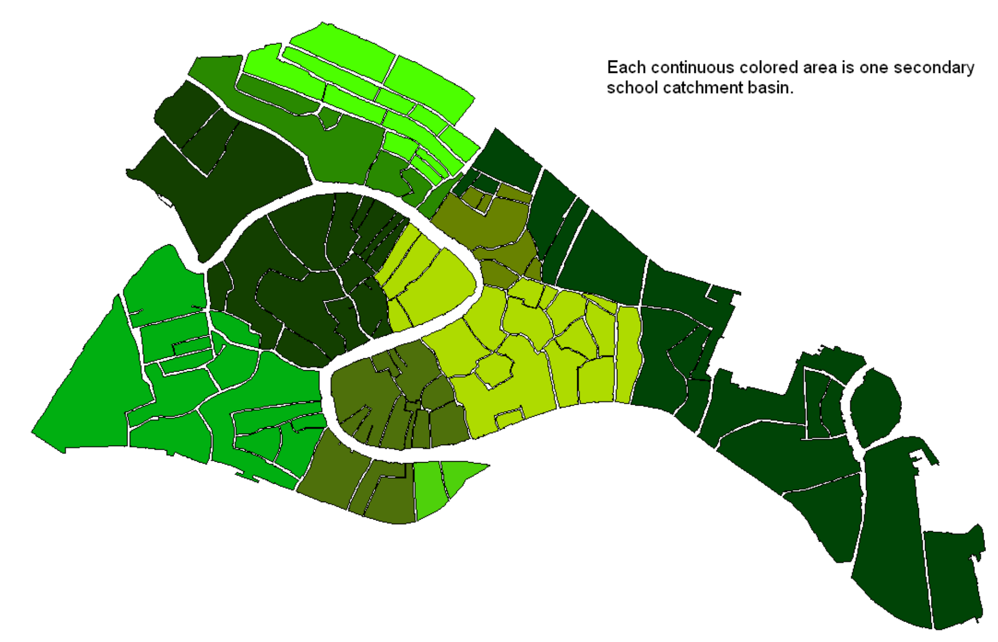


Figure 80 – Secondary School Catchment Basins by Island

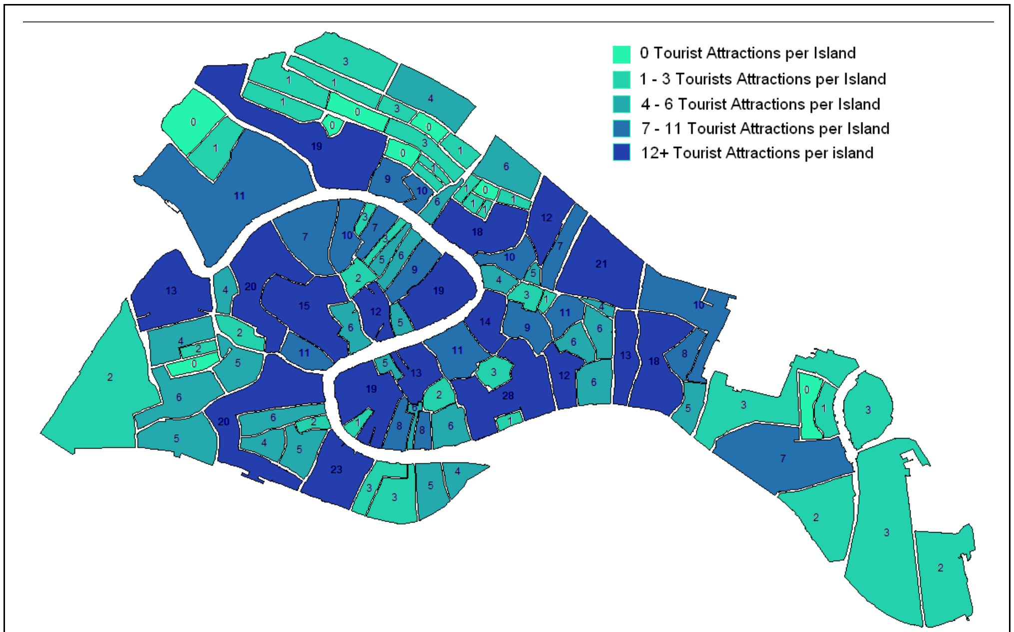


Figure 81 – Tourist Destinations by Island

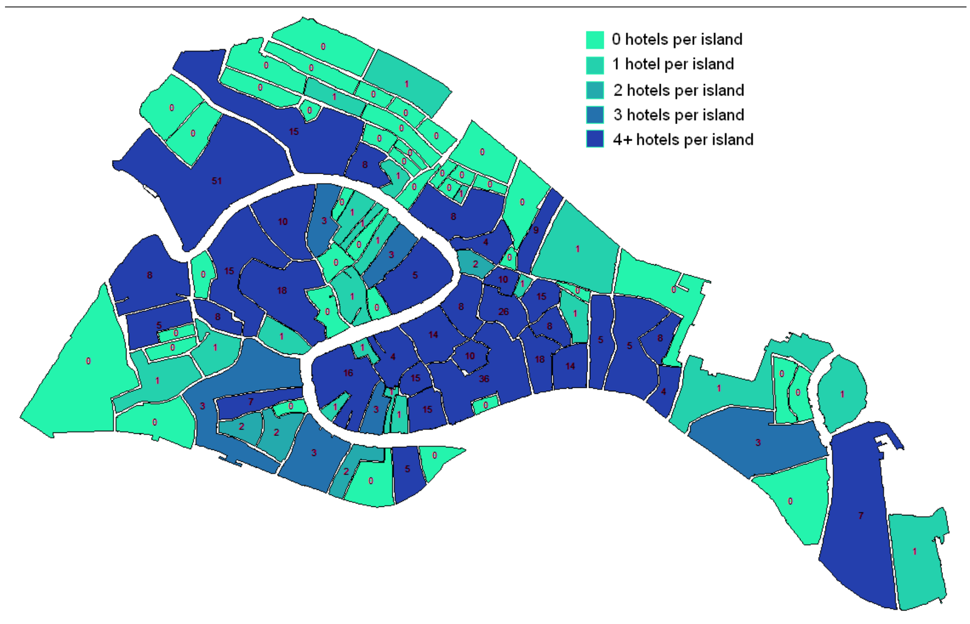


Figure 82 – Hotels by Island

Unlike Venetians, who will typically only have a few points of interest that they visit throughout the course of a day, tourists are much more likely to visit a variety of locations. The nature of these points of interest is also very different from that of Venetians. The areas that will be points of interest for the majority of tourists fall into the following categories: museums, churches, major shopping areas, outdoor recreation areas, and hotels. Figure 81 illustrates the locations of many of these non-hotel points of interest. This map was created as a conglomeration of previously existing maps of churches and green areas in Venice and adding additional points for known locations of museums. Figure 82 shows the locations of hotels in Venice. Hotels are to be treated as a unique type of tourist attraction because they are generally points of origin only at the beginning of the day and attractors only at the end of the day.

6.3.3 Temporal Information

In addition to each pedestrian having a set of points of interest that they will visit in a given day, they additionally have set or approximate quantities of time to spend at those points of interest and possible restrictions regarding the time at which they must be present at a destination, and the time by which they must no longer be at a point of interest. In practice, length of stay constraints correspond to the amount of time that is required for the pedestrian to complete all of the actions that they had wanted to complete that had caused them to travel to that point of interest. Other time constraints take the form of opening and closing times of attractions, schools, and work locations.

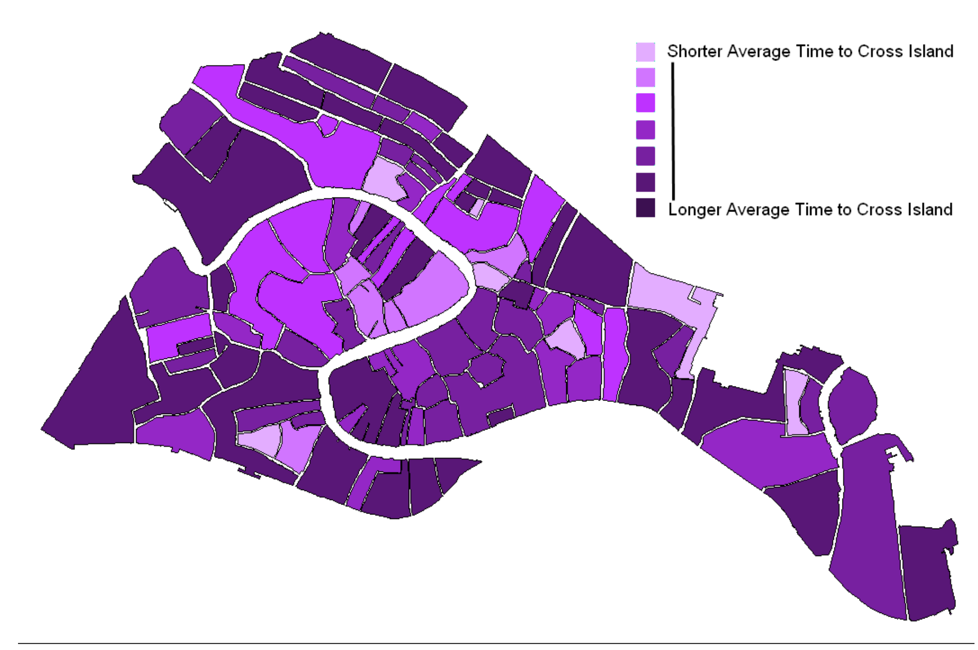
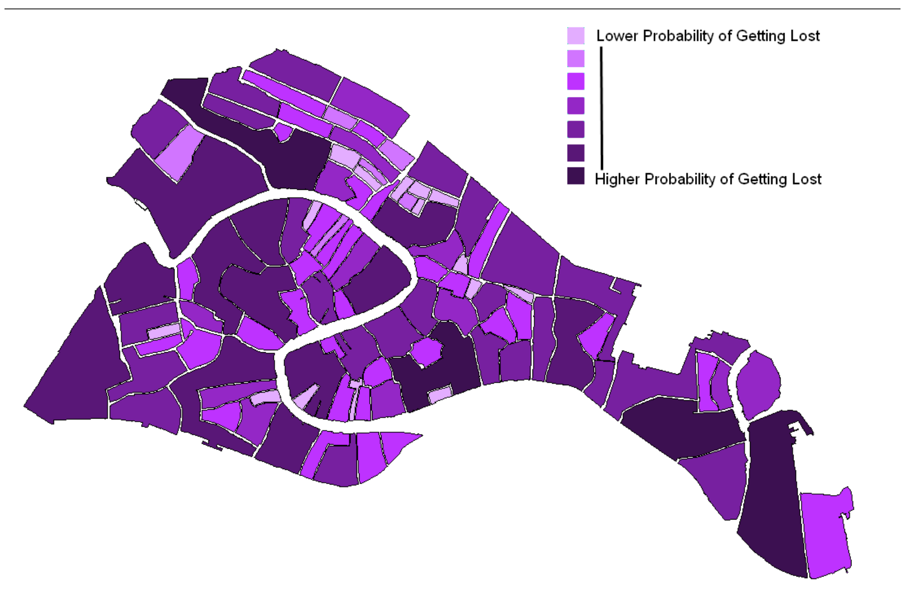


Figure 83 – Relative Distances Required to Cross Islands

There are also temporal considerations regarding the time that it takes for a pedestrian to move between various points in Venice. When a person decides whether to walk or to take a boat, they compare the approximate time required for each mode of transportation and typically choose the one that will be faster. An index of the number of minutes between boat stops for various lines can be found in the appendix. A general heuristic for the time required to move across an island is area of non-dead end pedestrian paths on that island. While it is know that this is not an optimal heuristic, and variables such as the lengths of such paths as opposed to areas and the actual distances between bridges could have been used to design a heuristic that could have potentially been more accurate, the area of non-dead end paths was chosen for its simplicity and ease of computation. Figure 83, the darker areas represent islands that on average require the traversal of a longer distance in order to cross and lighter areas require shorter distances. A legend is intentionally left off from of map because there is no easy way in which to compute a distance from the aforementioned heuristic; it is suitable only for comparative purposes.



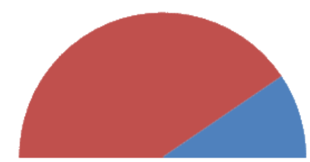


Figure 84 – Potential for Getting Lost	**Figure 85 – Ratio of Non-Dead ends to Dead Ends**

While Figure 83 sufficiently describes the time required to cross an island if the pedestrian has prior knowledge of the area and is consequently able to take the most direct route, tourists fall into a very different category. Venice is known for being somewhat of a maze to navigate. By area, 16% of pedestrian pathways in Venice are dead ends. Figure 86 displays all of the pedestrian pathways colored such that the red pathways are not dead ends and the blue pathways are dead ends. This high proportion of dead ends greatly adds to the amount of time that a typical pedestrian tourist would require to move across an island. The quantity of this increase in time can be approximated by measuring the areas of dead-end paths on each island. This comparative information is displayed for each island in Figure 84.

As with the previously discussed heuristic concerning the time required to cross an island in general, this type of heuristic is useful only for comparative purposes between various islands and a mapping between the quantities measured by this heuristic to an actual number for time increase has not developed. As is such, a legend was intentionally left off. In general, darker areas of the map correspond to islands on which a pedestrian who is unfamiliar with the terrain is more likely to get lost and consequently take sub-optimal paths. A more accurate heuristic might be to examine how far down a dead end a pedestrian would have to travel before realizing that that path was in fact a dead end and the proportion of dead ends which were likely to be chosen as possible paths, but such a heuristic is left as a future exercise.

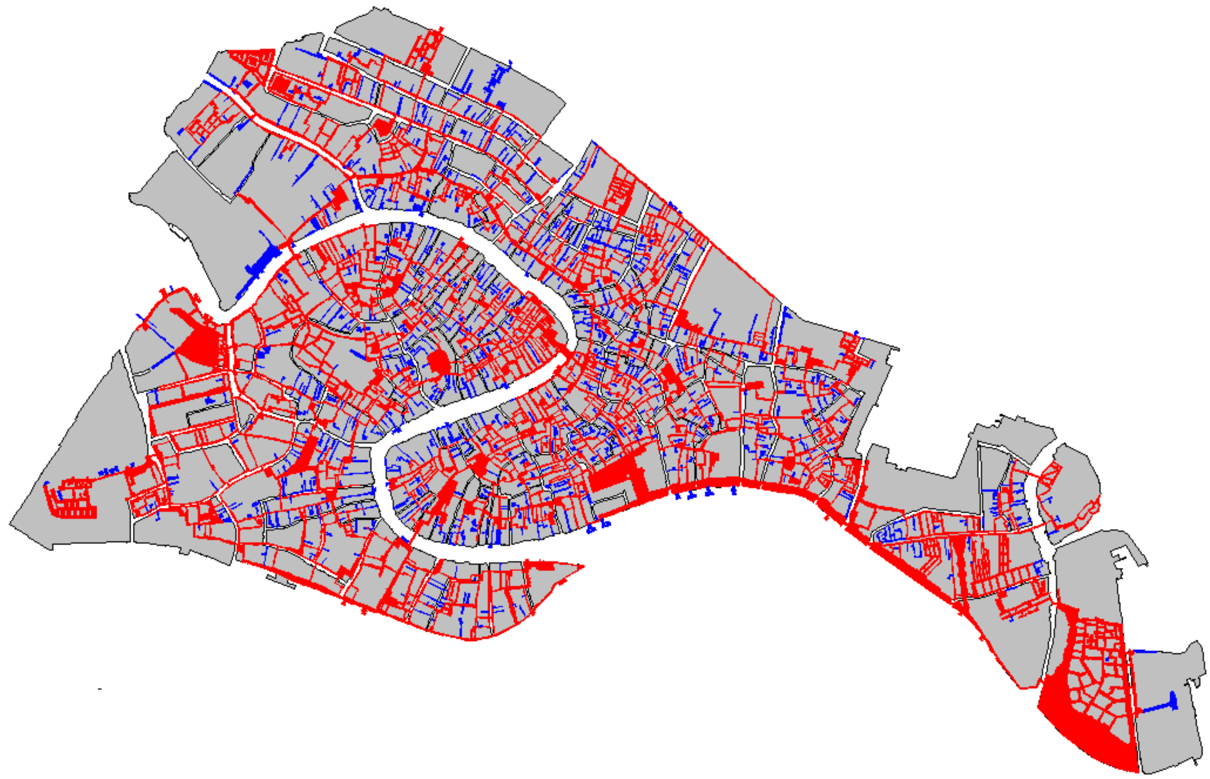


Figure 86 – Dead Ends in Venice
Blue streets represent dead-ends. Red passages are through-streets.

6.3.4 Graph-Theoretical Computer Model

A graph-theoretical model of Venice was needed in order to quantify the possible routes of pedestrian travel between individual islands. In this graph, each island was mapped to a node and each bridge to one or more edges. (A bridge was mapped to multiple edges when that bridge connected three or more islands). In this version of the graph, two island nodes were adjacent to each other if and only if there existed a public bridge connecting them. Private bridges were ignored because they do not allow for pedestrians to move between the two adjoined islands other than to reach a single location on one of the islands. The bridges that cross the Grand Canal are the largest bridges in Venice, with the most traffic going across them, and they take the longest amount of time to cross. Because of this, it was never desirable to cross the Grand Canal multiple times in the course of a single path traversal from origin to destination. In order to recreate this phenomenon, the graph-theoretical model was subdivided into two separate graphs, one for each side of the Grand Canal.

From the graph-theoretical model of Venice, a distance matrix was also created. This matrix labeled the number of islands which must be traversed in order to travel between any pair of islands, and was used in determining the intermediary islands to be traversed during a given path traversal.

6.3.5 Catchment Basins for ACTV Boat Stops

In order to determine which boat stop a pedestrian is most likely to travel to from a given point in Venice, catchment basins were created for each of the major ACTV boat lines. A catchment basin is the area which a particular boat stop is most likely to service. In the following set of maps, the green shaded maps display the overall boat stop catchment basins by island. Each color signifies a single catchment basin.

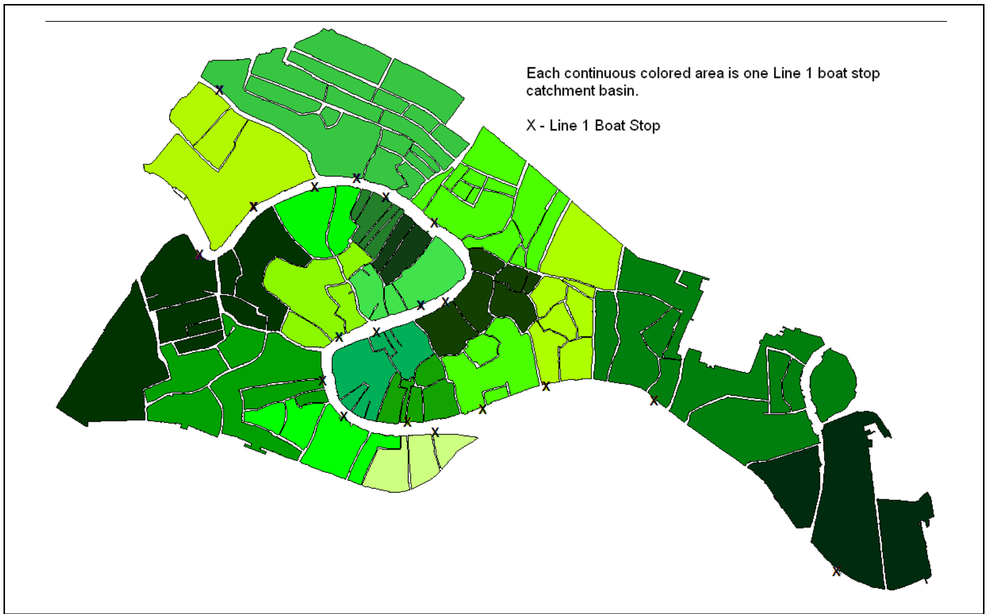


Figure 87 – Catchment Basins by Island for ACTV Line 1

Figure 88 – Distances to ACTV Line 1 Boat Stops by Island

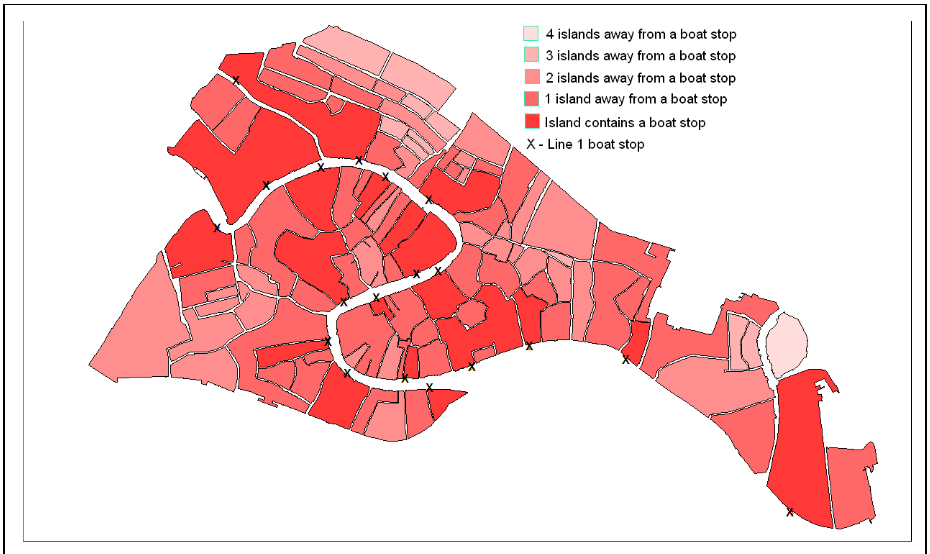


Figure 89 – Detailed Catchment Basins by Path for ACTV Line 1

For island level catchment basin analysis, the basins were determined by assigning an island to the catchment basin of the boat stop based on anticipated walking distance along pedestrian paths. As each island is more than a single point, there is not a unique distance from each island to each boat stop, so the following approximations were used. Every island that contained a boat stop was initially assigned to the catchment basin for that boat stop. After that, there was a balance between placing islands into the basin that they were the shortest physical distance from and placing islands in the basis that would require crossing the fewest bridges.

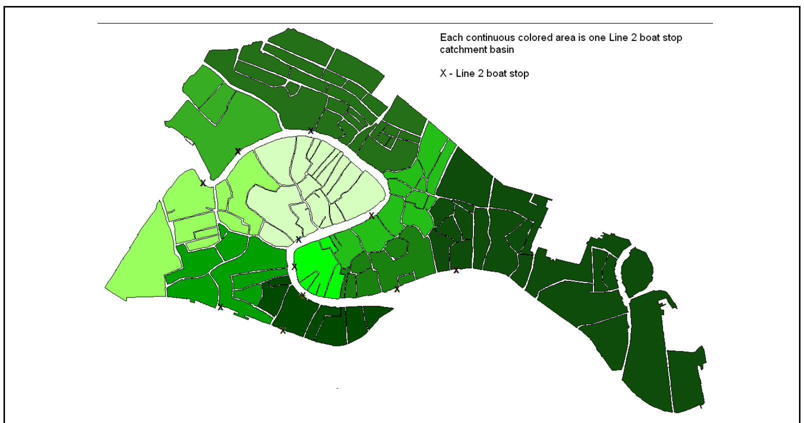


Figure 90 – Catchment Basins by Island for ACTV Line 2

Figure 91 – Detailed Catchment Basins for ACTV Line 2 by Path

For some of the lines, namely ACTV Line 1, ACTV Line 2, and ACTV line N, it was necessary to look at street level in order to accurately identify catchment basins because these boat stops all included islands on which there were two boat stops on one island. In these cases, the first step was to create an island-level catchment basin for both of the boat stops combined. A street-level model of the islands that made up that catchment basin was then analyzed to divide the pedestrian pathways into 2 catchment basins. These basins were determined by assigning each pathway to the catchment basin for the boat stop that was the shortest physical distance away by pedestrian paths. Theses distances were determined by utilizing MapInfo.

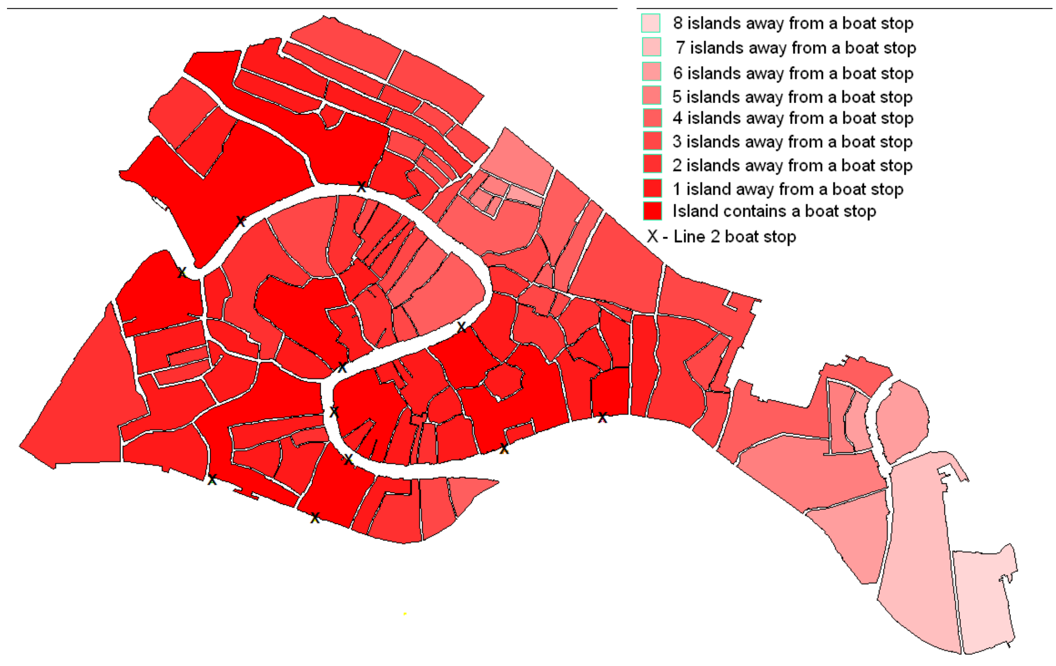


Figure 92 – Distances to ACTV Line 2 Boat Stops by Island

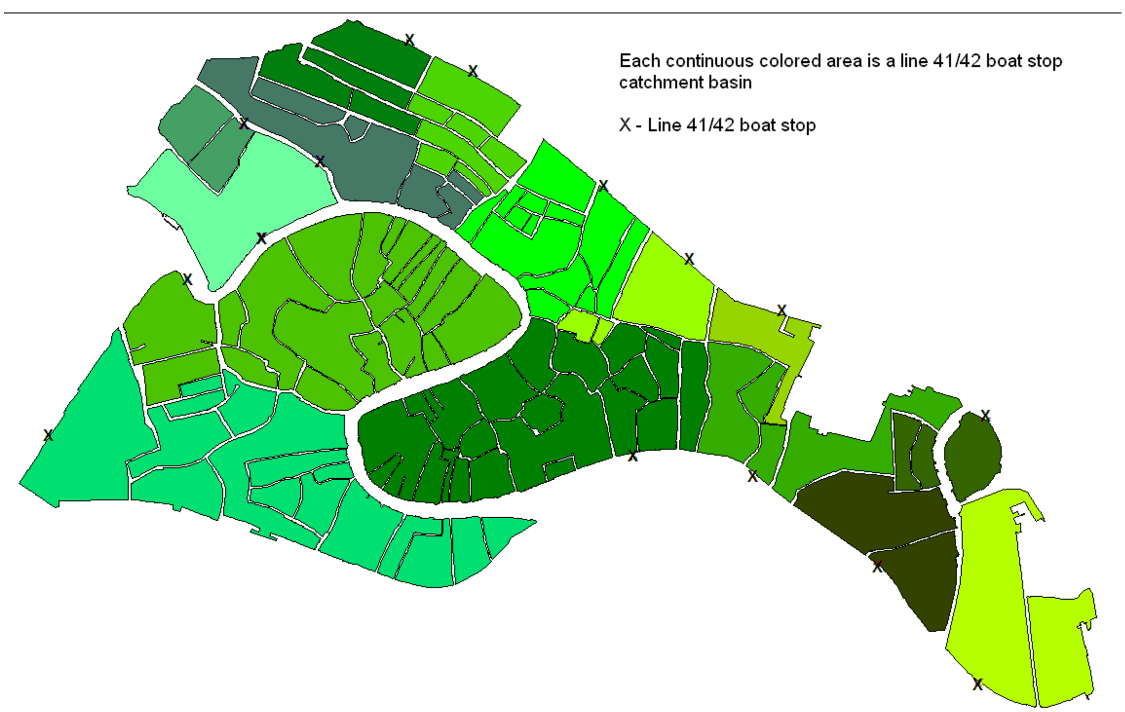


Figure 93 – Catchment Basins by Island for ACTV Lines 41/42

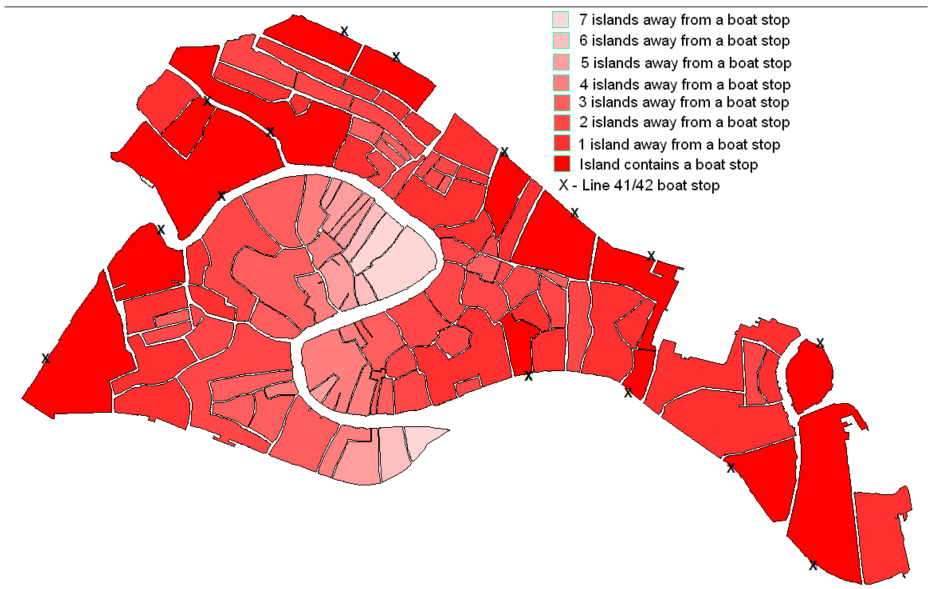


Figure 94 – Distances to ACTV Line 41/42 Boat Stops by Island

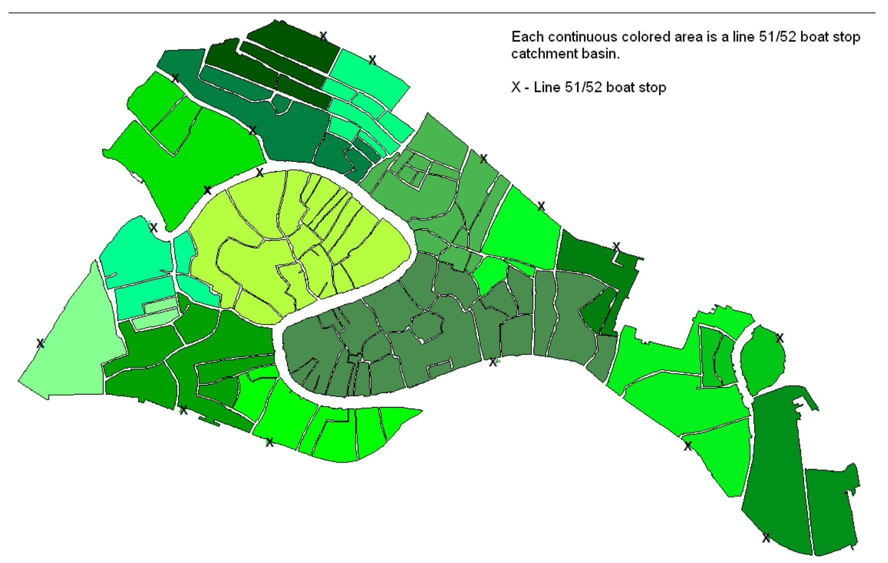


Figure 95 – Catchment Basins by Island for ACTV Lines 51/52

Once the basins had been determined, the next step was to correlate each island with a strength representing how likely a pedestrian is to utilize a particular boat line from their current location. A pedestrian being located in a particular catchment basin indicates that they will go to a boat stop on that particular boat line (provided they are willing to walk to the nearest boat stop). It does not, however, give any information about how likely they would actually utilize that boat line. Heat maps such as that shown in Figure 92 provide this dispersion information. In all of these maps, darker colors correspond to locations where a pedestrian is more likely to take a particular boat line. These were created with the recursive algorithm described below. (Note that the term “adjacent islands” refers to islands that are connected by one or more pedestrian bridges).

6.3.6 Intelligent Agent Movement within an Island

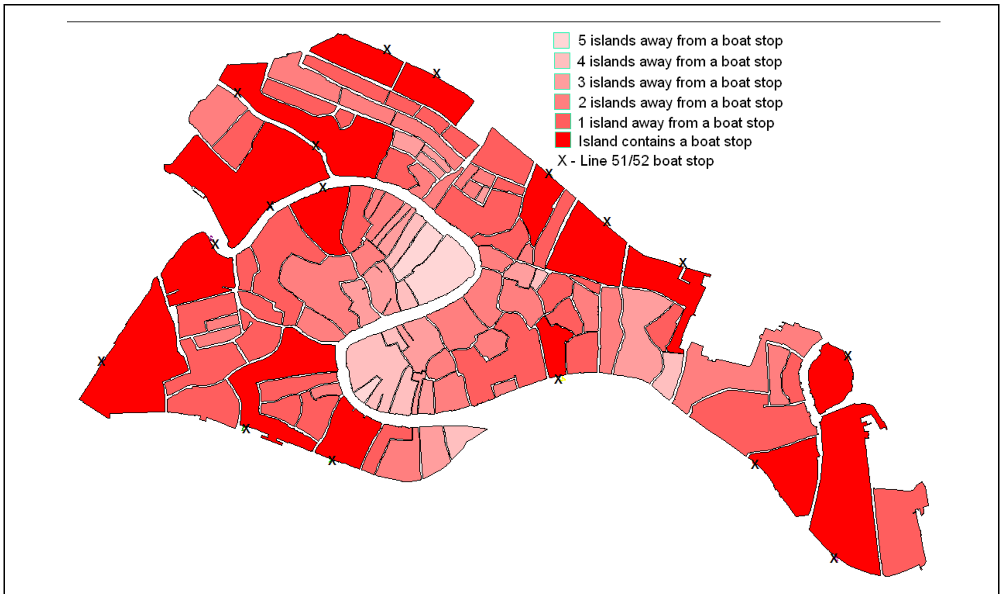


Figure 96 – Distances to ACTV Line 51/52 Boat Stops by Island

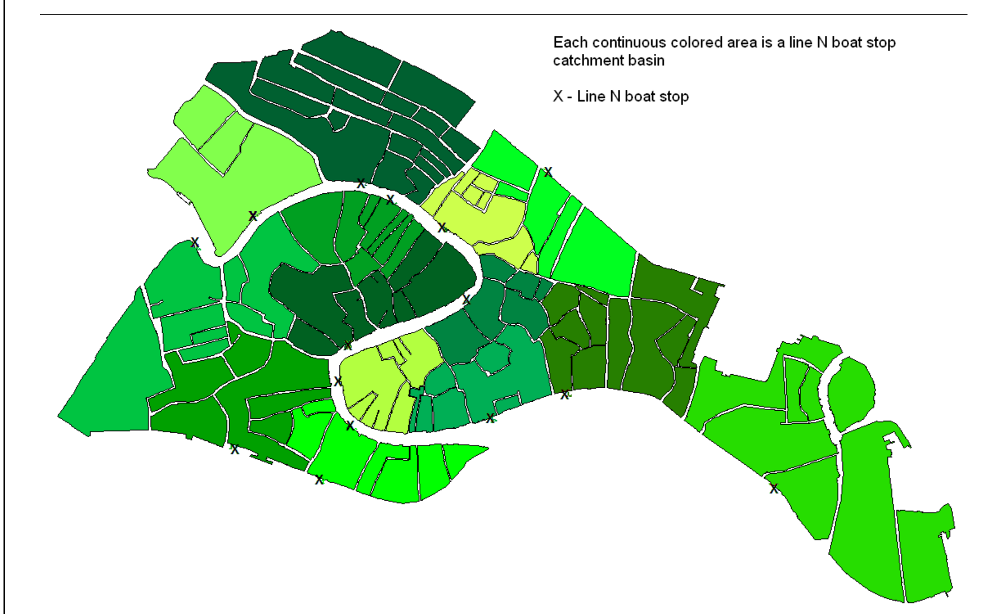


Figure 97 – Catchment Basins by Island for ACTV Line N Boat Stops

The model has the capability to show street-level movement of pedestrians. In order to accomplish this, the agents were made to have some degree of intelligence. The two primary tasks of an agent are first, to locate its target destination and second, to avoid obstacles such as walls and other agents. Whenever the model is looking at a street-level view, it is only looking at a single island. All of the agents in view have a destination, intermediary or permanent, on that island. Water-skiing algorithms are used to guide the pedestrians to their target destinations.

These algorithms work by assigning an ideal position beacon to each agent. This ideal position beacon travels along the path-level graph without regard to whether or not the agent is bumping into other agents. The ideal position beacon can search for the target destination by implying any of a number of graph-searching algorithms. The algorithm that is the most representative of actual pedestrian movement is a depth-first search. In this graph-searching algorithm, the agent moves down paths that will take it closer to its target destination as far as possible either until one of two end conditions is met: the target destination is found (in which case the algorithm terminates), or a point will be reached at which the agent has no options other than to retrace its steps (in this case, the agent moves back to the last point for which there was an option to take a direction that has not been taken yet, and moves in that direction). This repeats until the agent ultimately reaches its target destination.

Figure 98 – Catchment Basins for ACTV Line N Boat Stops by Path

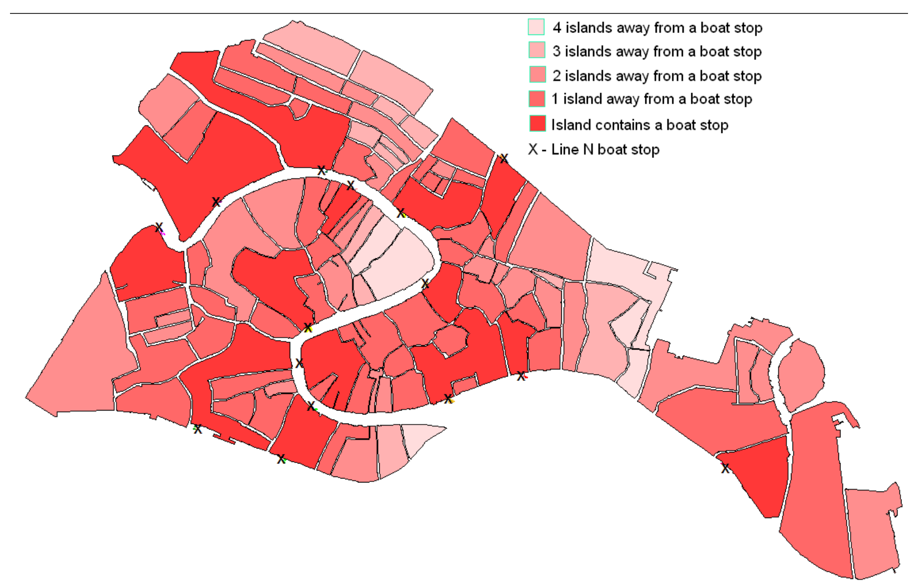


Figure 99 – Distances to ACTV Line N Boat Stops by Island

In a typical time step, the ideal position beacon should move a distance equal to the diameter of an agent in every time step. The position of the agent itself always has the target destination of the ideal position beacon. Unlike the traversal of the ideal-position beacon, the agent must avoid obstacles and be conscious of other agents. To do this, the agents always check the location where they about to move before moving there. If there is another agent in that position, the first agent must then either wait, or move in a slightly different direction. The ideal position beacon shouldn't move forward until the actual agent is within 1 agent distance of the beacon.

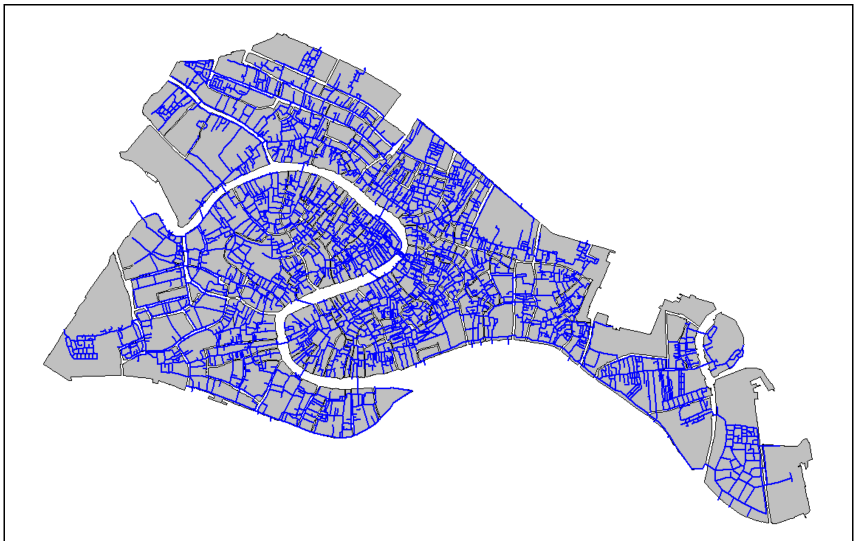


Figure 100 – Path Level Graph-Theoretical Model

6.4 Modeling Results (Preliminary Computer Model)

This project created a preliminary computer model, including the code basis for creating an interactive autonomous-agent modeling program.

6.4.1 Implementation of Computer Model

While most of the time and energy of the project was devoted to collecting and analyzing mobility data, as well as to the development the theoretical model of mobility in Venice, preliminary work in creating an actualized computer model of the theoretical model was started.

6.4.1.1 Programming Platform (Panda 3D)

In order to begin work on the computer model of Venetian mobility, it was first necessary to examine those characteristics of the theoretical model that would have the largest impact on our choice of graphical framework. The most pressing aspect to consider was the tens-of-thousands, if not hundreds-of-thousands of autonomous agents that would need to be simulated simultaneously. This condition necessitated choosing a framework that was robust and efficient enough to handle the processing of this large number of mobile, real-time objects. The second consideration, closely tied to the first, was that the mobile autonomous agents not only had to perceive and interact with their virtual surroundings, but also come in several varieties, ranging from tourists and Venetians to people with luggage, carts, or other mobility impairments. It follows that the chosen framework would have to support object-oriented programming and class inheritance, to enable the creation of many different and complex types of agents by building upon simple base agents, in contrast to having to explicitly build each agent type up from bottom to top. Finally, considering the short amount of time given to develop the model (one seven- week IQP term), the framework needed to be relatively easy to use and supported by copious documentation and active support facilities.

Luckily, one graphical framework was found that addressed each of the above-mentioned conditions. The framework chosen was *Panda3D*[24], a free and open source 3D game development engine developed by Disney and Carnegie Mellon. The *Panda3D* libraries support writing applications in both *Python* and *C++*, both well known object-oriented languages. *Panda3D* is the graphics core of the Venetian boat model created by Redfish, and is also currently used in two Disney "Massively Mulitplayer Online Role Playing Games" (MMORPG): "*Toontown*"[25] and "Pirates of the Caribbean Online"[26]. Both *MMORPG*s show the capability of the *Panda3D* engine to support large numbers of objects interacting in large-scale environments. Lastly, *Panda3D* is well documented and has an active community support forum.

6.4.1.1.1 Programming with Python

Python was chosen as the application language due to its ease of use, dexterity, and efficiency. Much of the sample code was written in *Python*, and using *Python* for this model made it easier to leverage the existing code.

6.4.1.2 Computer Model Structure

The computer simulated model of Venetian mobility consists of several main components. The first component is the "world", a simulated environment consisting of static, stationary objects such as bridges, islands, pathways, and obstacles that the mobile autonomous agents interact with. The second group of components is the autonomous agents themselves. These agents exist within the world and

[24] http://www.panda3d.org
[25] http://www.toontown.com
[26] http://piratesonline.go.com

interact with it, as well as with each other. The third and final component is the user interface, which controls how potential users can interact with and view the model.

6.4.1.3 The World within the Computer Model

The world was initially developed in *MapInfo*. *MapInfo* is a GIS visualization tool that uses a proprietary "*.tab*" format in order to store map objects. This format is very useful in its versatility and inherent ability to link all objects into databases, where information relating to the objects can be conveniently stored, but it suffers from the shortcoming that it supports many types of objects that are not supported by other file formats. Consequently, care must be taken to cleanse the files before any conversion can take place.

There were two map layers used in the model: islands and pedestrian paths in Venice. There were preliminary versions of both of these map layers in existence prior to the beginning of this IQP, but both layers required substantial adjustments before they were suitable for input into the computer model. The pedestrian path layer consisted of a set of approximately 3,800 polygonal objects that combine to represent all areas in Venice that can be used for pedestrian mobility. The most important adjustment made was to redesign some of the objects in the pedestrian path layer so that each object consisted of a single, closed polygon. The shapes that comprised the pedestrians paths had to be closely examined so as to make sure that every boundary between adjacent path objects was smooth and without gaps; whenever a gap was discovered, one or both of the objects on either side of the gap were manually adjusted. In addition to making adjustments necessary to conform to the standards of the file formats that these objects were to be transferred to, it was also necessary to ensure that each path object either corresponded to a bridge or was entirely contained within the boundaries of a single island. This was accomplished by subdividing any objects that did not meet this requirement. The last change that needed to be made to the pedestrian path map layer was to remove areas that corresponded to private bridges. While these areas technically are accessible to the public, they cannot be used to traverse Venice beyond travel to the one specific point at the end of the private bridge and thus a decision was made to eliminate these from the mobility model for Venice as any traffic that occurs across them is negligible. Since the model required the ability to display only those paths which are on a particular island, the pedestrian path map layer was subdivided into a separate layer for each island and a layer for bridges. The original version of the island map layer conformed to all of the standards that would be necessary for file conversion. The only change made was to remove the objects for some of the islands so as to make the map in the model correspond only to the portion of Venice that was under consideration for this project.

Once the Map Info layers were completed, it was necessary to convert them to *.egg* files for input into the Panda 3D framework. A two-step conversion process was used to accomplish this. The first step was to use a Google Earth Link plug in for *MapInfo* that easily converted the *.tab* files into ".*kml"* files. One *.kml* file was created for each map layer. Prior to this project, there did not exist a compiler that was capable of converting *.kml* files to egg files. As both of these file formats are plain text readable, it was possible to develop such a compiler without too much difficulty. The compiler first extracted the GPS coordinates and the order in which to connect them from the *.kml* file by searching for lines that contained numbers that corresponded to coordinates located in Venice. The *.kml* file innately stores coordinates in the order in which they are to be connected, so determining the order was a simple as keeping track of the order in which they were read in. The compiler then had to generate the text for the *.egg* file that would allow the *Panda3D* loader to recognize the file as an *.egg* file and to insert to recorded GPS coordinate information into the appropriate location in the *.egg* file. While there was only one *.kml* file per *MapInfo* layer, an *.egg* file is only capable of storing information about a single map object, so the compiler also handled the organization of these files in a way in which the organization initially created by having the various MapInfo layers would not be lost.

Once the *.egg* files were generated, they were placed in a hierarchal folder structure, with groups of objects that were to be imported together, such as pathways on a particular island, in the same folder. This structure enabled the use of simple loading calls when it was determined that a certain subset of the world needed to be loaded.

6.4.1.4 User Interface of the Computer Model

With the limited amount of time and resources available to the developing the computer model, it was decided that a simple and intuitive user interface would be the option for end-user interaction with the model. Since the simulation world shared many qualities consistent with a 2-dimensional map, the interface designed was based on one of the leading map environments currently available: *Google Maps*[27]. A small set of the features present in *Google Maps* were implemented in the *Panda3D* world, namely click-and-drag map scrolling, and mouse-wheel zoom. With click-and-drag scrolling, the user can

[27] http://maps.google.com

change their subject of interest by placing the mouse pointer over a desired section of the map and (while holding down the secondary mouse button) move the mouse pointer to the center of the screen. When the user performs these actions, the desired section of the map is brought to the center of the screen in a one-to-one movement corresponding to the mouse movement. This interface mechanism is both highly intuitive and simple to implement, requiring only knowledge of the mouse position and current location of the user's view. The second user interface feature was mouse-wheel zoom. To operate this function, the user merely rolls the scroll wheel on the mouse forward to zoom in to the section of the map currently in the center of the screen, and rolls the scroll wheel backwards to zoom out. By combining both of these features together, the user is able to manipulate their effective position over the map in the three 3-dimensional axis, x, y, and z, giving the illusion of looking down upon a real map.

6.4.1.5 Pedestrian Framework used in the Computer Model

After generating the world and a user interface to allow interaction with and viewing of the world, the world was populated by autonomous agents, the main "working parts" of the model. The process of populating the model was carried out in several steps. The first step was to design and construct the autonomous "people," placing the agents on the map, and finally giving them destinations and allowing them to run their behaviors.

One of the primary reasons for advocating for a model designed in an object-oriented language such as *Python* was to enable the use of base classes of agents to design and construct more complex agent classes, without having to build each new agent class from scratch. In order to allow for more complex agents and behavior, a base class needed to be constructed, with qualities that all future autonomous agent "people" would inherit.

6.4.1.5.1 Capabilities of Autonomous Agents in the Computer Model (Basic AI)

Due to the complexities involved in creating autonomous agent behaviors, it was decided to focus on a select group of simple yet important behaviors. These behaviors were "moving forward," "turning," checking a location in the world for the presence of objects (called "point checking"), and dealing with objects directly in front of the agent ("obstacle avoidance.") The "move forward" and "turning" behaviors were the simplest to implement, with "turning" merely changing the agent's heading by a given number of degrees, and "moving forward" consisting of setting the agents location to be a given distance from its previous position along the agent's heading. One of the more complex behaviors, “point checking,” allows the agent to query what objects are at any location on the map. The result of this check, whether or not there is an object at the given location, is then fed to the last behavior, “obstacle avoidance.” The “obstacle avoidance” behavior, upon activation by the “point check” behavior, proceeds to check the points directly to the left and right of the agent. If either of those spots are clear the behavior dictates turning to face the open spot, otherwise, the agent simply turns to face the opposite direction to its previous heading. By combining these behaviors together, the agents were able enact a rudimentary “wander” behavior, where the agents randomly moved forward or turned, making sure to turn again to avoid obstacles if any were encountered.

6.4.1.5.2 Origins and Destinations of Autonomous Agents

In addition to the “wander” behavior, the basic “person” agent can enact a rudimentary “destination seeking” behavior. When created, the agent is placed at an initial pre-defined “source” location and is given a pre-defined “destination” location. The “destination seeking” behavior works by having the agent turn to face the direction of its destination, followed by moving forward. This behavior allows an agent to exhibit more realistic behavior than simply wandering around. This behavior is limited, however, because if the agent encounters an obstacle, the agent will become “stuck” behind that obstacle, lacking the intelligence necessary to reconcile turning away to avoid the obstacle, and turning towards its destination to move closer to the goal.

6.4.1.5.3 Obstacle Avoidance by Autonomous Agents

One objective of the overall model is to anticipate possible mobility patterns when new obstacles are placed in the path of traffic flow, such as café tables or scaffolding. As a proof of concept to realizing this study in the complete computer simulation, a real-time object placement system was developed. This system consists of the user choosing a desired location by moving the mouse cursor over that location, followed by pressing the designated keyboard button (t) to place a square shaped object at that location. Multiple table objects may be inserted at various locations, and they appear as obstacles to the agents when queried.

6.5 Computer Model Recommendations

The modeling section of this project still needs plenty of work to get off the ground. Someone trained in this specific branch of computer science would be greatly helpful to get this model to the point specified in this report. Someone with fewer qualifications is unlikely to complete the creation of this model with the complexity and power required for its uses. From there, other IQP groups should be able to add data to this model with relative ease, constantly improving the accuracy of this system. The model has been outline in detail here, and once all specifications have been met, it will be a sustaining and adaptable method of describing the city of Venice.

As always, this field of study can be broadened and strengthened. This project group is providing the backbone of IQP work on comprehensive Venetian mobility. The counting regimen can be strengthened, and the modeling work needs to be completed by an individual that knows how, with the assistance of the framework in this report. Work will always go on, and the Venice Mobility 2009 team hopes that the body of work completed this team will be built upon to further understand the uniqueness of mobility in the city of Venice.

7 Conclusions

This group completed a major undertaking with one of the largest and most successful data collection campaigns, with 4 people logging over 3 million data points in less than five weeks. The data collected is usable for an autonomous agent-based computer model. This model has been researched and developed, culminating in a basic functioning model with a plan for future groups to complete this work. It was simply not feasible to both collect a staggering amount of data and produce a professional-caliber Artificial Intelligence computer model in such a short time. Instead, enough has been done to greatly help the next group, and provide seeding for a new project.

The data that has been collected is extremely interesting and helpful to the city and other groups. An agent-based model of the city of Venice could provide emergency responders and other city officials with a way to test plans for emergency response, construction, and public space management in a controlled environment before deploying any real-world solutions.

8 Bibliography

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9 Appendices

Included below is supplemental information in support of analyses and assertions made in this report.

9.1 Bridge Codes, Locations, and Counting Location

Bridge Code	Bridge Category	Bridge Name	Latitude (decimal)	Longitude (decimal)	Pedestrians Counted From
1	Primary	Ponte della Paglia	45.433673°	12.341055°	West
2	Primary	Ponte dei Bareteri	45.436101°	12.337620°	Southeast
3	Primary	1.Ponte de l'Ovo	45.436540°	12.335820°	East
4	Primary	Ponte della Costituzione	45.438903°	12.319407°	South
5	Primary	Ponte della Madoneta	45.437220°	12.330763°	West
6	Primary	Ponte de Cannaregio de la Guglie	45.443680°	12.325557°	East
7	Primary	Ponte delle Sechere	45.438050°	12.322963°	West
8	Primary	Ponte dei Scalzi	45.441143°	12.322705°	South
9	Primary	Ponte de Rialto	45.438008°	12.335914°	Northwest
10	Primary	Ponte dell'Accademia	45.431691°	12.328939°	Southwest
11	Primary	Ponte della Veneta Marina de le Codene	45.432056°	12.350639°	West
12	Primary	Ponte Nuovo di San Felice	45.441523°	12.333434°	Southeast
13	Primary	Ponte della Canonica	45.434940°	12.340547°	West
14	Primary	Ponte Santi Apostali	45.440086°	12.336465°	South
A	Secondary	Ponte del Forno	45.434700°	12.323107°	West
B	Secondary	Ponte S. Margherita	45.435364°	12.324160°	Northeast
C	Secondary	Ponte Foscari	45.434757°	12.325931°	North
D	Secondary	Ponte della Frescada	45.435446°	12.327046°	South
E	Secondary	Ponte Giovanni Andrea de la Croce	45.439640°	12.331673°	Southeast
F	Secondary	Ponte dei Frati	45.434197°	12.331510°	East
G	Secondary	Ponte de San Vio	45.430621°	12.329868°	Northwest
H	Secondary	Ponte delle Ostreghe	45.432491°	12.333494°	Northeast
I	Secondary	Ponte Sansovino	45.432539°	12.337585°	East
J	Secondary	Ponte del Mondo Novo	45.437111°	12.340404°	South
K	Secondary	Ponte del Vin	45.433840°	12.342278°	East
L	Secondary	Ponte della Pieta'	45.434018°	12.344392°	East
M	Secondary	Ponte del Sepolcro	45.433933°	12.345377°	East
N	Secondary	Ponte Ca' di Dio	45.433471°	12.348107°	West

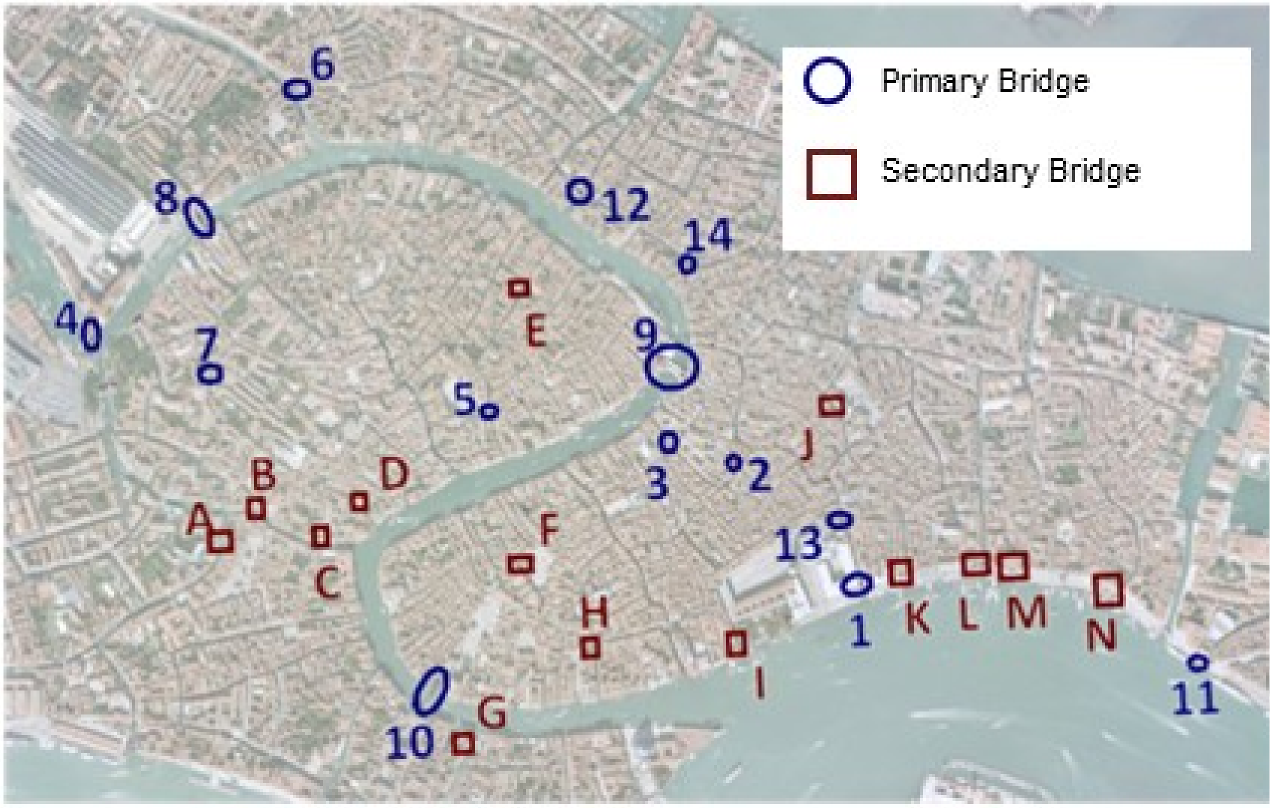

Figure 101 – Map of Analyzed Bridges

9.2 Island Identification Numbers

Figure 102 – Map of Island Identification Numbers

9.3 ACTV Boat Line Map

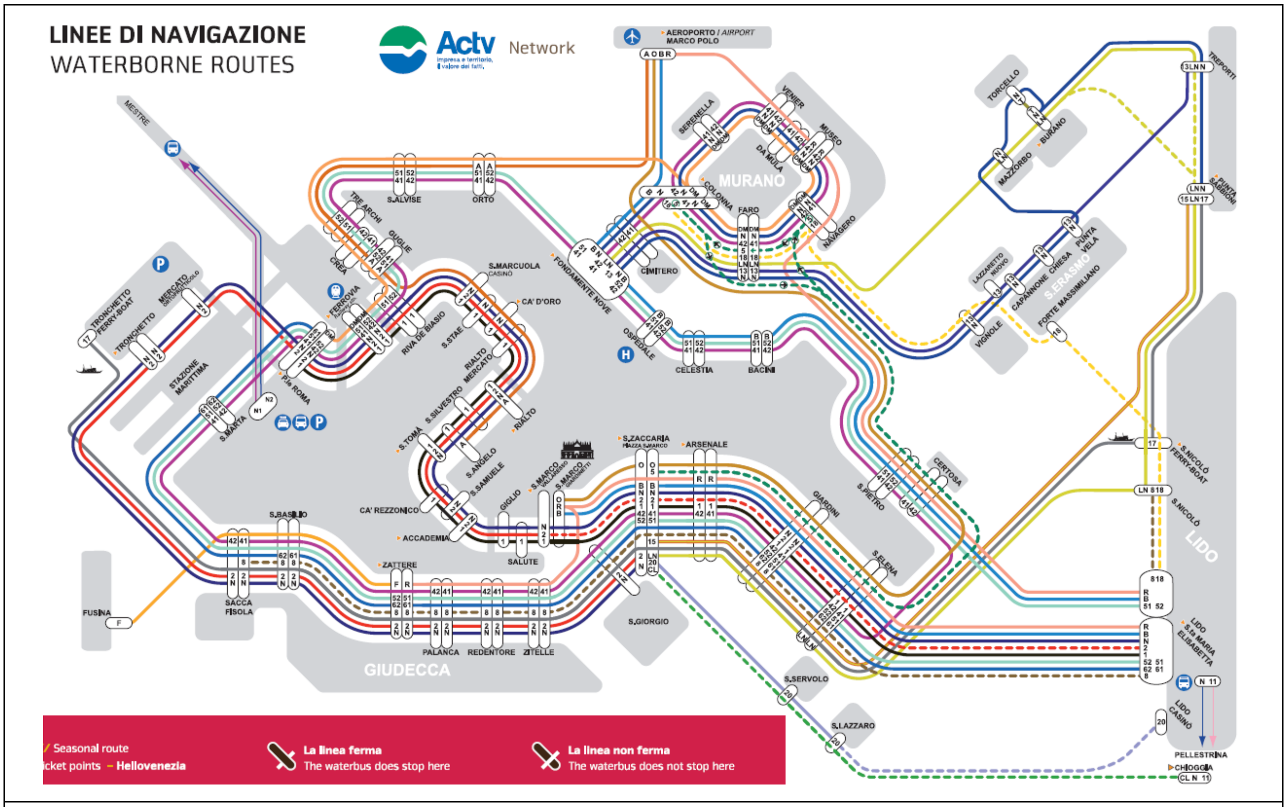

Figure 103 – ACTV Boat Line Map

9.4 Maps of Overall Pedestrian Dispersion by Time

The sizes of the arrows directly correlate to the number of people crossing per minute. The direction of the arrows indicates the direction of net traffic flow. The color of the arrow indicates the strength of the net flow. Yellow is used when the net flow is zero or close to zero and colors farther from yellow in rainbow order are used to indicate stronger net flows in either direction. Colors tending towards red and tending towards blue are used for opposite directions of flow.

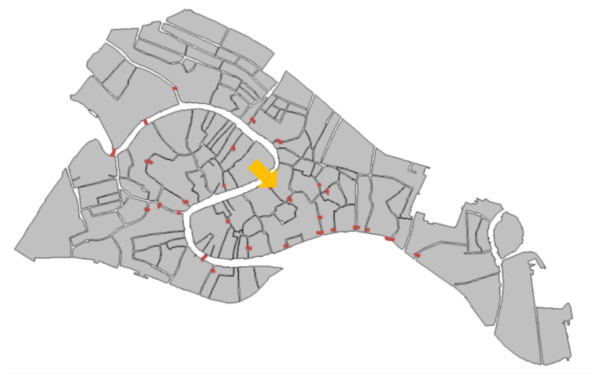

Figure 104 – Overall Pedestrian Flow in Venice (7 AM — 8 AM)

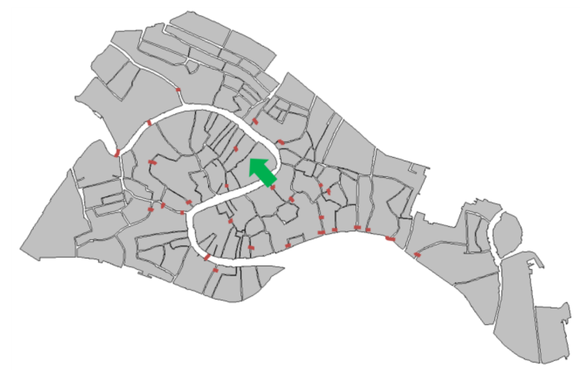

Figure 105 – Overall Pedestrian Flow in Venice (8 AM — 9 AM)

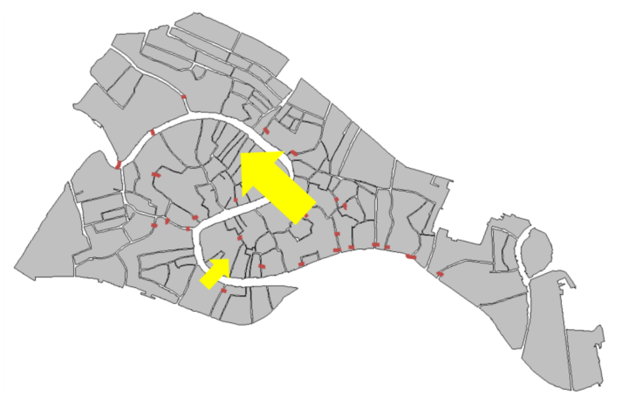

Figure 106 – Overall Pedestrian Flow in Venice (9 AM — 10 AM)

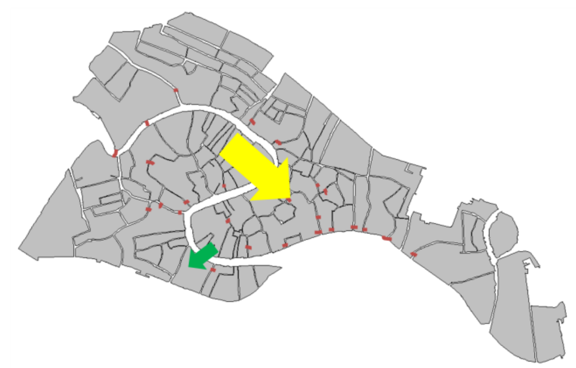

Figure 107 – Overall Pedestrian Flow in Venice (10 AM — 11 AM)

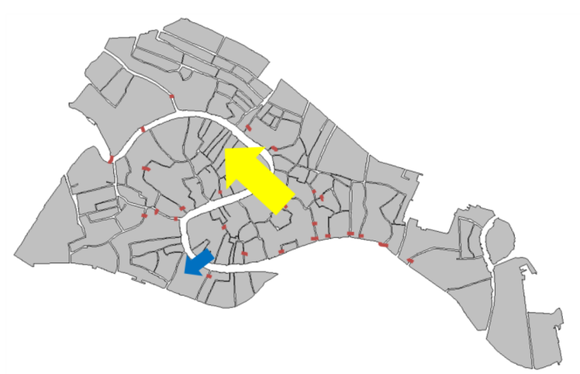

Figure 108 – Overall Pedestrian Flow in Venice (11 AM — 12 PM)

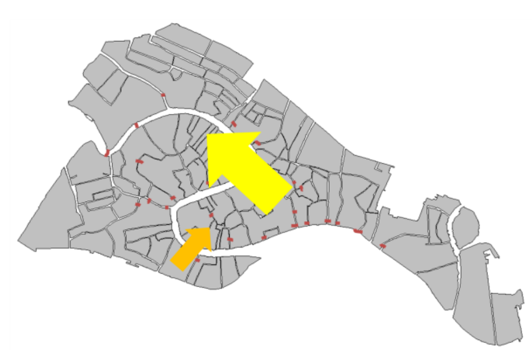

Figure 109 – Overall Pedestrian Flow in Venice (12 PM — 1 PM)

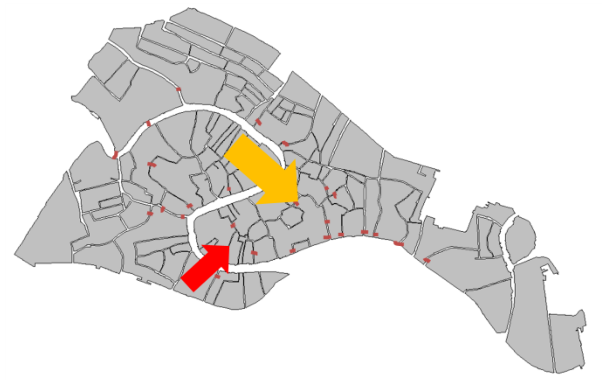

Figure 110 – Overall Pedestrian Flow in Venice (1 PM — 2 PM)

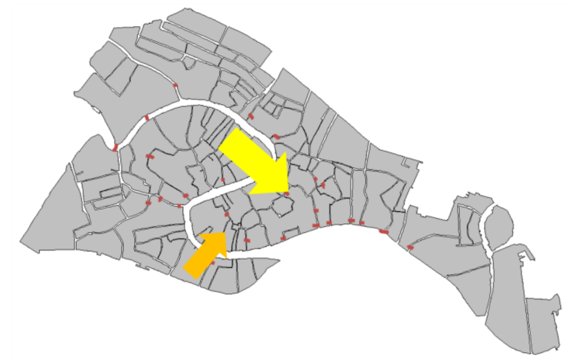

Figure 111 – Overall Pedestrian Flow in Venice (2 PM — 3 PM)

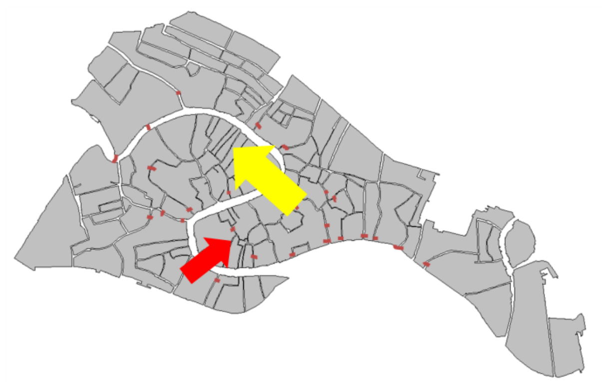

Figure 112 – Overall Pedestrian Flow in Venice (3 PM — 4 PM)

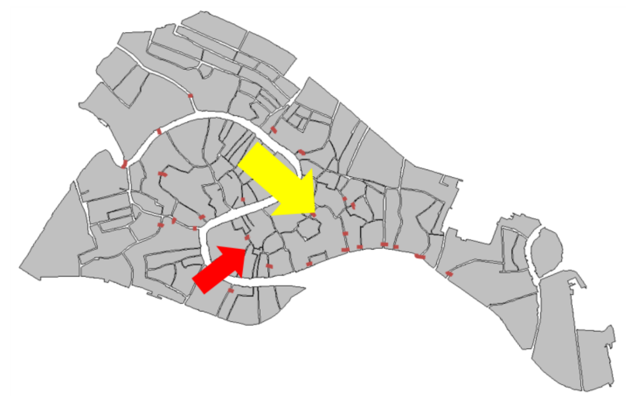

Figure 113 – Overall Pedestrian Flow in Venice (4 PM — 5 PM)

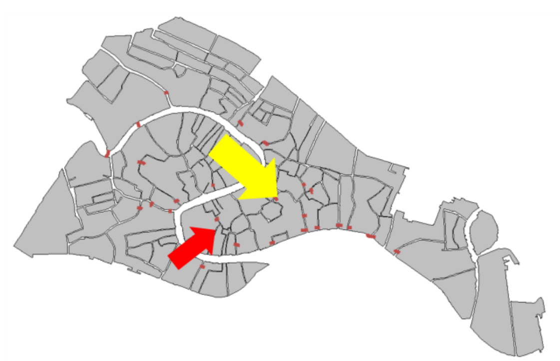

Figure 114 – Overall Pedestrian Flow in Venice (5 PM — 6 PM)

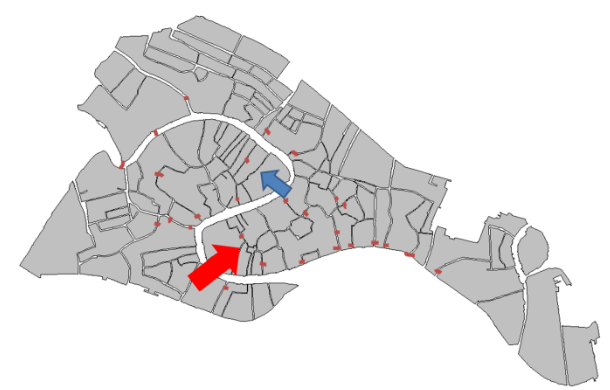

Figure 115 – Overall Pedestrian Flow in Venice (6 PM — 7 PM)

9.5 ACTV Travel Times by Boat Line

ACTV Boat Line #1

Time Between Boat Stops in Minutes

	P Roma	Ferrovia	Riva De Biasio	S Marcuola	S Stae	Ca D'Oro	Rialto Mercato	Rialto	S Silvestro	S Angelo	S Toma	Ca Rezzonico	Accademia	Giglio	Salute	S Marco	S Zaccaria	Arsenale	Giardini	S Elena
P Roma	0	3	6	8	10	13	16	19	22	24	26	29	31	34	36	39	43	46	49	53
Ferrovia	3	0	3	5	7	10	13	16	19	21	23	26	28	31	33	36	40	43	46	50
Riva De Biasio	6	3	0	2	4	7	10	13	16	18	20	23	25	28	30	33	37	40	43	47
S Marcuola	9	6	3	0	2	5	8	11	14	16	18	21	23	26	28	31	35	38	41	45
S Stae	11	8	5	2	0	3	6	9	12	14	16	19	21	24	26	29	33	36	39	43
Ca D'Oro	13	10	7	4	2	0	3	6	9	11	13	16	18	21	23	26	30	33	36	40
Rialto Mercato	16	13	10	7	5	3	0	3	6	8	10	13	15	18	20	23	27	30	33	37
Rialto	19	16	13	10	8	6	3	0	3	5	7	10	12	15	17	20	24	27	30	34
S Silvestro	22	19	16	13	11	9	6	3	0	2	4	7	9	12	14	17	21	24	27	31
S Angelo	24	21	18	15	13	11	8	5	2	0	2	5	7	10	12	15	19	22	25	29
S Toma	26	23	20	17	15	13	10	7	4	2	0	3	5	8	10	13	17	20	23	27
Ca Rezzonico	29	26	23	20	18	16	13	10	7	5	3	0	2	5	7	10	14	17	20	24
Accademia	31	28	25	22	20	18	15	12	9	7	5	2	0	3	5	8	12	15	18	22
Giglio	34	31	28	25	23	21	18	15	12	10	8	5	3	0	2	5	9	12	15	19
Salute	36	33	30	27	25	23	20	17	14	12	10	7	5	2	0	3	7	10	13	17
S Marco	39	36	33	30	28	26	23	20	17	15	13	10	8	5	3	0	4	7	10	14
S Zaccaria	43	40	37	34	32	30	27	24	21	19	17	14	12	9	7	4	0	3	6	10
Arsenale	46	43	40	37	35	33	30	27	24	22	20	17	15	12	10	7	3	0	3	7
Giardini	49	46	43	40	38	36	33	30	27	25	23	20	18	15	13	10	6	3	0	4
S Elena	53	50	47	44	42	40	37	34	31	29	27	24	22	19	17	14	10	7	4	0

9.6 Distance Matrix Graph-Theoretical Model of Venice

ACTV Boat Line #2
Time Between Boat Stops in Minutes

	S Zaccaria	Zattere	S Basilio	P Roma	Ferrovia	Rialto	S Toma	S Samuele	Accademia	S Marco
S Zaccaria	0	14	17	38	42	52	57	60	62	66
Zattere	15	0	3	24	28	38	43	46	48	52
S Basilio	17	2	0	21	25	35	40	43	45	49

P Roma	38	23	21	0	4	14	19	22	24	28
Ferrovia	42	27	25	4	0	10	15	18	20	24
Rialto	52	37	35	14	10	0	5	8	10	14
S Toma	57	42	40	19	15	5	0	3	5	9
S Samuele	60	45	43	22	18	8	3	0	2	6
Accademia	62	47	45	24	20	10	5	2	0	4
S Marco	67	52	50	29	25	15	10	7	5	0

ACTV Boat Line #41
Time Between Boat Stops in Minutes

	F. Te. Nove	Orto	S Alvise	Crea	Guglie	Ferrovia	P le Roma	S Marta	S Zaccaria	Arsenale	Giardini	S Elena	S Pietro	Bacini	Celestia	Ospedale
F. Te. Nove	0	75	73	68	64	59	56	50	33	30	27	24	15	7	4	2
Orto	5	0	78	73	69	64	61	55	38	35	32	29	20	12	9	7
S Alvise	7	2	0	75	71	66	63	57	40	37	34	31	22	14	11	9
Crea	12	7	5	0	76	71	68	62	45	42	39	36	27	19	16	14
Guglie	16	11	9	4	0	75	72	66	49	46	43	40	31	23	20	18
Ferrovia	21	16	14	9	5	0	77	71	54	51	48	45	36	28	25	23
P le Roma	24	19	17	12	8	3	0	74	57	54	51	48	39	31	28	26
S Marta	30	25	23	18	14	9	6	0	63	60	57	54	45	37	34	32
S Zaccaria	47	42	40	35	31	26	23	17	0	77	74	71	62	54	51	49
Arsenale	50	45	43	38	34	29	26	20	3	0	77	74	65	57	54	52
Giardini	53	48	46	41	37	32	29	23	6	3	0	77	68	60	57	55
S Elena	56	51	49	44	40	35	32	26	9	6	3	0	71	63	60	58
S Pietro	65	60	58	53	49	44	41	35	18	15	12	9	0	72	69	67
Bacini	72	67	65	60	56	51	48	42	25	22	19	16	7	0	76	74
Celestia	76	71	69	64	60	55	52	46	29	26	23	20	11	4	0	78
Ospedale	78	73	71	66	62	57	54	48	31	28	25	22	13	6	2	0

ACTV Boat Line #42
Time Between Boat Stops in Minutes

	F. Te. Nove	Ospedale	Celestia	Bacini	S Pietro	S Elena	Giardini	Arsenale	S Zaccaria	S Marta	P Roma	Ferrovia	Crea	S Alvise	Orto
F. Te. Nove	0	80	78	75	68	59	56	53	50	33	27	23	14	9	7
Ospedale	2	0	80	77	70	61	58	55	52	35	29	25	16	11	9
Celestia	4	2	0	79	72	63	60	57	54	37	31	27	18	13	11
Bacini	7	5	3	0	75	66	63	60	57	40	34	30	21	16	14
S Pietro	14	12	10	7	0	73	70	67	64	47	41	37	28	23	21
S Elena	23	21	19	16	9	0	79	76	73	56	50	46	37	32	30

Giardini	26	24	22	19	12	3	0	79	76	59	53	49	40	35	33
Arsenale	29	27	25	22	15	6	3	0	79	62	56	52	43	38	36
S Zaccaria	32	30	28	25	18	9	6	3	0	65	59	55	46	41	39
S Marta	49	47	45	42	35	26	23	20	17	0	76	72	63	58	56
P Roma	55	53	51	48	41	32	29	26	23	6	0	78	69	64	62
Ferrovia	59	57	55	52	45	36	33	30	27	10	4	0	73	68	66
Crea	68	66	64	61	54	45	42	39	36	19	13	9	0	77	75
S Alvise	73	71	69	66	59	50	47	44	41	24	18	14	5	0	80
Orto	75	73	71	68	61	52	49	46	43	26	20	16	7	2	0

ACTV Boat Line #51
Time Between Boat Stops in Minutes

	S Pietro	Bacini	Celestia	Ospedale	F. Te Nove	Orto	S. Alvise	Tre Archi	Guglie	Riva de Biasio	Ferrovia	P Roma	S Marta	Zattere	S Zaccaria	Giardini	S Elena
S Pietro	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Bacini	7	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Celestia	9	2	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Ospedale	12	5	3	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
F. Te. Nove	14	7	5	2	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Orto	19	12	10	7	5	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
S Alvise	21	14	12	9	7	2	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Tre Archi	26	19	17	14	12	7	5	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Guglie	30	23	21	18	16	11	9	4	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Riva de Biasio	32	25	23	20	18	13	11	6	2	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Ferrovia	35	28	26	23	21	16	14	9	5	3	0	n/a	n/a	n/a	n/a	n/a	n/a
P. Roma	38	31	29	26	24	19	17	12	8	6	3	0	n/a	n/a	n/a	n/a	n/a
S. Marta	44	37	35	32	30	25	23	18	14	12	9	6	0	n/a	n/a	n/a	n/a
Zattere	51	44	42	39	37	32	30	25	21	19	16	13	7	0	n/a	n/a	n/a
S. Zaccaria	5	51	49	46	44	39	37	32	28	26	23	20	14	7	0	n/	n/

	8															a	a
Giardini	63	56	54	51	49	44	42	37	33	31	28	25	19	12	5	0	n/a
S. Elena	67	60	58	55	53	48	46	41	37	35	32	29	23	16	9	4	0

ACTV Boat Line #52
Time Between Boat Stops in Minutes

	S. Elena	Giardini	S. Zaccaria	Zattere	S. Marta	P. Roma	Ferrovia	Riva de Biasio	Guglie	Tre Archi	S Alvise	Orto	F. Te. Nove	Ospedale	Celestia	Bacini	S Pietro
S. Elena	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Giardini	4	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
S. Zaccaria	9	5	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Zattere	16	12	7	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
S. Marta	23	19	14	7	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
P. Roma	29	25	20	13	6	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Ferrovia	33	29	24	17	10	4	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Riva de Biasio	35	31	26	19	12	6	2	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Guglie	37	33	28	21	14	8	4	2	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Tre Archi	41	37	32	25	18	12	8	6	4	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a
S Alvise	46	42	37	30	23	17	13	11	9	5	0	n/a	n/a	n/a	n/a	n/a	n/a
Orto	48	44	39	32	25	19	15	13	11	7	2	0	n/a	n/a	n/a	n/a	n/a
F. Te. Nove	53	49	44	37	30	24	20	18	16	12	7	5	0	n/a	n/a	n/a	n/a
Ospedale	56	52	47	40	33	27	23	21	19	15	10	8	3	0	n/a	n/a	n/a
Celestia	58	54	49	42	35	29	25	23	21	17	12	10	5	2	0	n/a	n/a
Bacini	60	56	51	44	37	31	27	25	23	19	14	12	7	4	2	0	n/a
S Pietro	67	63	58	51	44	38	34	32	30	26	21	19	14	11	9	7	0

ACTV Boat Line N (Night) Time Between Boat Stops in Minutes													
	S Zaccaria	Zattere	S. Basilio	P. Roma	Ferrovia	S. Marcuola	S. Stae	Ca D'Oro	Rialto	S. Toma	S. Samuele	Accademia	S. Marco
S Zaccaria	0	12	19	39	42	46	48	50	54	59	61	63	67
Zattere	14	0	7	27	30	34	36	38	42	47	49	51	55
S. Basilio	19	5	0	20	23	27	29	31	35	40	42	44	48
P. Roma	39	25	20	0	3	7	9	11	15	20	22	24	28
Ferrovia	42	28	23	3	0	4	6	8	12	17	19	21	25
S. Marcuola	46	32	27	7	4	0	2	4	8	13	15	17	21
S. Stae	48	34	29	9	6	2	0	2	6	11	13	15	19
Ca D'Oro	50	36	31	11	8	4	2	0	4	9	11	13	17
Rialto	56	42	37	17	14	10	8	6	0	5	7	9	13
S. Toma	59	45	40	20	17	13	11	9	3	0	2	4	8
S. Samuele	61	47	42	22	19	15	13	11	5	2	0	2	6
Accademia	63	49	44	24	21	17	15	13	7	4	2	0	4
S. Marco	67	53	48	28	25	21	19	17	11	8	6	2	0

9.7 Boat Data Collected at San Michele Cemetery

A short boat traffic count was taken at Venice's cemetery island, San Michele, on All Souls Day.

Boat Stop	Boat Number	Boat Line	Direction	Time	# Onto Island	# Off of Island
South	*	-	South	10:10	9	0
South	8459	42	South	10:15	33	0
South	8459	-	North	10:16	0	31
South	8432	-	South	10:21	46	0
South	8432	-	North	10:24	0	20
South	*	-	South	10:26	21	6
South	*	-	South	10:28	13	0
South	7688	-	South	10:35	0	68
South	8865	42	North	10:37	52	0
South	8410	13	South	10:39	17	0
South	7688	-	South	10:40	14	0
South	8432	-	North	10:43	0	23
South	8057	41	South	10:47	29	5
South	8432	-	South	10:49	16	0
South	*	42	South	10:54	25	1
South	7688	-	North	10:56	0	23

9.8 Rialto Photo Spreadsheet

Rialto Bridge-Tourists v. Venetians						
Time	Picture ID	# of tourists	#of venetians	% tourists	% Venetians	location
7:00	DSCN0262.jpg	0	0	#DIV/0!	#DIV/0!	NE
7:00	DSCN0263.jpg	0	0	#DIV/0!	#DIV/0!	NW
7:01	DSCN0264.jpg	0	3	0	100	CW
7:01	DSCN0265.jpg	0	4	0	100	CE
7:01	DSCN0266.jpg	0	0	#DIV/0!	#DIV/0!	SW
7:01	DSCN0267.jpg	0	0	#DIV/0!	#DIV/0!	SE
7:01	DSCN0268.jpg	0	0	#DIV/0!	#DIV/0!	NC
7:06	DSCN0269.jpg	3	2	60	40	SW
7:06	DSCN0270.jpg	0	2	0	100	NW
7:07	DSCN0271.jpg	1	1	50	50	SW
7:10	DSCN0272.jpg	2	0	100	0	SC
7:11	DSCN0273.jpg	2	0	100	0	SC
7:12	DSCN0274.jpg	0	0	#DIV/0!	#DIV/0!	NW
7:12	DSCN0275.jpg	2	1	66.6666667	33.3333333	NE
7:13	DSCN0276.jpg	3	3	50	50	SC
7:13	DSCN0277.jpg	0	2	0	100	CW
7:13	DSCN0278.jpg	0	3	0	100	CE
7:13	DSCN0279.jpg	2	0	100	0	SW
7:14	DSCN0280.jpg	0	2	0	100	SE
7:14	DSCN0281.jpg	3	0	100	0	NC
7:23	DSCN0282.jpg	1	0	100	0	SC
7:23	DSCN0283.jpg	0	1	0	100	NW
7:23	DSCN0284.jpg	4	0	100	0	NE
7:23	DSCN0285.jpg	4	5	44.4444444	55.5555556	CW
7:23	DSCN0286.jpg	1	0	100	0	CE
7:23	DSCN0287.jpg	0	1	0	100	SW
7:23	DSCN0288.jpg	1	0	100	0	SE
7:24	DSCN0289.jpg	1	3	25	75	NC
7:35	DSCN0294.jpg	3	0	100	0	SC
7:35	DSCN0295.jpg	0	1	0	100	NW
7:35	DSCN0296.jpg	0	0	#DIV/0!	#DIV/0!	NE
7:35	DSCN0297.jpg	0	1	0	100	CW
7:35	DSCN0299.jpg	0	0	#DIV/0!	#DIV/0!	CE
7:35	DSCN0300.jpg	0	0	#DIV/0!	#DIV/0!	SW
7:35	DSCN0301.jpg	1	2	33.3333333	66.6666667	SE
7:35	DSCN0302.jpg	0	0	#DIV/0!	#DIV/0!	NC

7:41	DSCN0306.jpg	1	0	100	0	SC
7:41	DSCN0307.jpg	1	0	100	0	NW
7:42	DSCN0308.jpg	5	0	100	0	SE
7:42	DSCN0309.jpg	3	1	75	25	CW
7:42	DSCN0310.jpg	0	0	#DIV/0!	#DIV/0!	CE
7:42	DSCN0311.jpg	1	1	50	50	NE
7:42	DSCN0312.jpg	1	1	50	50	SW
7:42	DSCN0313.jpg	0	0	#DIV/0!	#DIV/0!	NC
7:50	DSCN0317.jpg	5	0	100	0	SC
7:51	DSCN0318.jpg	1	1	50	50	NW
7:51	DSCN0319.jpg	0	3	0	100	SW
7:51	DSCN0320.jpg	0	0	#DIV/0!	#DIV/0!	CW
7:51	DSCN0321.jpg	0	0	#DIV/0!	#DIV/0!	CE
7:51	DSCN0322.jpg	0	0	#DIV/0!	#DIV/0!	NE
7:51	DSCN0323.jpg	0	0	#DIV/0!	#DIV/0!	SE
7:52	DSCN0324.jpg	0	0	#DIV/0!	#DIV/0!	SC
7:54	DSCN0327.jpg	7	0	100	0	SW
7:54	DSCN0328.jpg	3	0	100	0	NE
7:54	DSCN0330.jpg	0	0	#DIV/0!	#DIV/0!	NC
8:03	DSCN0340.jpg	4	1	80	20	SC
8:03	DSCN0341.jpg	0	0	#DIV/0!	#DIV/0!	NW
8:03	DSCN0342.jpg	0	1	0	100	NE
8:03	DSCN0343.jpg	4	4	50	50	CW
8:03	DSCN0344.jpg	0	0	#DIV/0!	#DIV/0!	CE
8:03	DSCN0345.jpg	1	1	50	50	SW
8:04	DSCN0346.jpg	2	1	66.6666667	33.3333333	SE
8:04	DSCN0347.jpg	0	2	0	100	SC
8:05	DSCN0351.jpg	4	1	80	20	CW
8:13	DSCN0356.jpg	4	0	100	0	SC
8:13	DSCN0357.jpg	0	0	#DIV/0!	#DIV/0!	SW
8:13	DSCN0358.jpg	0	1	0	100	NW
8:13	DSCN0359.jpg	3	4	42.8571429	57.1428571	CW
8:13	DSCN0360.jpg	0	1	0	100	CE
8:14	DSCN0361.jpg	0	1	0	100	SW
8:14	DSCN0362.jpg	2	1	66.6666667	33.3333333	SE
8:14	DSCN0363.jpg	0	1	0	100	NC
8:15	DSCN0367.jpg	1	2	33.3333333	66.6666667	NE
8:21	DSCN0371.jpg	5	3	62.5	37.5	SC
8:21	DSCN0372.jpg	0	2	0	100	NW
8:21	DSCN0374.jpg	0	4	0	100	CW

8:21	DSCN0375.jpg	2	2	50	50	CE
8:21	DSCN0376.jpg	1	0	100	0	SW
8:21	DSCN0377.jpg	1	2	33.3333333	66.6666667	SE
8:21	DSCN0380.jpg	3	1	75	25	NC
8:22	DSCN0382.jpg	2	1	66.6666667	33.3333333	CE
8:34	DSCN0383.jpg	10	1	90.9090909	9.09090909	SC
8:34	DSCN0384.jpg	0	2	0	100	NW
8:34	DSCN0385.jpg	0	2	0	100	NE
8:34	DSCN0386.jpg	2	3	40	60	CW
8:34	DSCN0387.jpg	2	5	28.5714286	71.4285714	CE
8:34	DSCN0388.jpg	2	3	40	60	SW
8:34	DSCN0389.jpg	4	0	100	0	SE
8:36	DSCN0393.jpg	1	2	33.3333333	66.6666667	NC
8:37	DSCN0394.jpg	4	0	100	0	SC
8:41	DSCN0398.jpg	0	1	0	100	NW
8:42	DSCN0399.jpg	0	2	0	100	SW
8:42	DSCN0400.jpg	1	5	16.6666667	83.3333333	CW
8:42	DSCN0401.jpg	1	3	25	75	CE
8:42	DSCN0402.jpg	2	1	66.6666667	33.3333333	SW
8:42	DSCN0403.jpg	4	2	66.6666667	33.3333333	SE
8:50	DSCN0410.jpg	5	1	83.3333333	16.6666667	SC
8:50	DSCN0411.jpg	0	1	0	100	NW
8:50	DSCN0412.jpg	1	0	100	0	NE
8:50	DSCN0413.jpg	2	2	50	50	CW
8:51	DSCN0416.jpg	2	2	50	50	CE
8:51	DSCN0417.jpg	2	1	66.6666667	33.3333333	SW
8:51	DSCN0418.jpg	7	1	87.5	12.5	SE
8:52	DSCN0420.jpg	1	2	33.3333333	66.6666667	NC
9:00	DSCN0424.jpg	6	2	75	25	SC
9:00	DSCN0425.jpg	0	0	#DIV/0!	#DIV/0!	NW
9:00	DSCN0426.jpg	1	1	50	50	NE
9:02	DSCN0428.jpg	3	5	37.5	62.5	CW
9:02	DSCN0429.jpg	0	3	0	100	CE
9:03	DSCN0430.jpg	5	1	83.3333333	16.6666667	SW
9:03	DSCN0431.jpg	5	1	83.3333333	16.6666667	SE
9:03	DSCN0432.jpg	7	0	100	0	NC
9:12	DSCN0433.jpg	10	3	76.9230769	23.0769231	SC
9:12	DSCN0434.jpg	0	1	0	100	NW
9:12	DSCN0435.jpg	2	0	100	0	NE
9:13	DSCN0436.jpg	3	5	37.5	62.5	CW

9:13	DSCN0437.jpg	3	5	37.5	62.5	CE
9:13	DSCN0438.jpg	0	0	#DIV/0!	#DIV/0!	SW
9:13	DSCN0439.jpg	6	2	75	25	SE
9:13	DSCN0440.jpg	6	2	75	25	NC
9:23	DSCN0441.jpg	11	1	91.6666667	8.33333333	SC
9:23	DSCN0442.jpg	2	0	100	0	NW
9:23	DSCN0444.jpg	2	3	40	60	CW
9:23	DSCN0446.jpg	4	3	57.1428571	42.8571429	CE
9:23	DSCN0447.jpg	5	2	71.4285714	28.5714286	SW
9:23	DSCN0448.jpg	9	0	100	0	SE
9:23	DSCN0449.jpg	11	1	91.6666667	8.33333333	NC
9:32	DSCN0454.jpg	10	0	100	0	SC
9:32	DSCN0455.jpg	1	3	25	75	NW
9:32	DSCN0456.jpg	4	1	80	20	NE
9:32	DSCN0457.jpg	11	3	78.5714286	21.4285714	CW
9:32	DSCN0458.jpg	3	1	75	25	CE
9:33	DSCN0459.jpg	4	3	57.1428571	42.8571429	SW
9:33	DSCN0460.jpg	6	0	100	0	SE
9:33	DSCN0461.jpg	12	1	92.3076923	7.69230769	NC
10:06	DSCN0462.jpg	17	3	85	15	SC
10:08	DSCN0466.jpg	3	2	60	40	NE
10:12	DSCN0471.jpg	5	3	62.5	37.5	CE
10:12	DSCN0472.jpg	9	1	90	10	CW
10:31	DSCN0478.jpg	0	1	0	100	NW
10:32	DSCN0479.jpg	20	2	90.9090909	9.09090909	SC
10:33	DSCN0480.jpg	6	1	85.7142857	14.2857143	NE
10:47	DSCN0487.jpg	14	0	100	0	SE
15:58	DSCN0712.jpg	27	2	93.1034483	6.89655172	SC
15:58	DSCN0713.jpg	9	1	90	10	NE
15:58	DSCN0714.jpg	6	0	100	0	NW
15:58	DSCN0715.jpg	7	2	100	0	CE
15:58	DSCN0716.jpg	7	3	70	30	CW
15:59	DSCN0718.jpg	9	2	81.8181818	18.1818182	SE
15:59	DSCN0720.jpg	9	0	100	0	SW
15:59	DSCN0721.jpg	14	1	93.3333333	6.66666667	NC
16:08	DSCN0734.jpg	28	2	93.3333333	6.66666667	SC
16:09	DSCN0735.jpg	10	1	90.9090909	9.09090909	NW
16:09	DSCN0736.jpg	9	0	100	0	NE
16:09	DSCN0737.jpg	5	2	71.4285714	28.5714286	CW
16:09	DSCN0738.jpg	10	3	76.9230769	23.0769231	CE

16:09	DSCN0740.jpg	16	0	100	0	SW
16:09	DSCN0742.jpg	20	0	100	0	SE
16:10	DSCN0743.jpg	18	1	94.7368421	5.26315789	NC
16:16	DSCN0753.jpg	18	0	100	0	SW
16:18	DSCN0754.jpg	20	2	90.9090909	9.09090909	SC
16:18	DSCN0755.jpg	4	3	57.1428571	42.8571429	NW
16:18	DSCN0756.jpg	14	0	100	0	NE
16:18	DSCN0757.jpg	13	1	92.8571429	7.14285714	CW
16:18	DSCN0758.jpg	10	1	90.9090909	9.09090909	CE
16:18	DSCN0759.jpg	18	0	100	0	SW
16:19	DSCN0763.jpg	17	0	100	0	SE
16:19	DSCN0764.jpg	21	0	100	0	NC
16:29	DSCN0778.jpg	21	0	100	0	SC
16:29	DSCN0779.jpg	9	1	90	10	NW
16:29	DSCN0780.jpg	9	0	100	0	NE
16:29	DSCN0781.jpg	10	1	90.9090909	9.09090909	CW
16:30	DSCN0783.jpg	11	1	91.6666667	8.33333333	CE
16:30	DSCN0785.jpg	11	0	100	0	SW
16:30	DSCN0786.jpg	7	1	87.5	12.5	SE
16:30	DSCN0787.jpg	10	1	90.9090909	9.09090909	NC
16:38	DSCN0810.jpg	3	0	100	0	NW
16:38	DSCN0811.jpg	3	1	75	25	NE
16:39	DSCN0812.jpg	14	1	93.3333333	6.66666667	CW
16:39	DSCN0813.jpg	7	2	77.7777778	22.2222222	CE
16:40	DSCN0815.jpg	10	1	90.9090909	9.09090909	SW
16:40	DSCN0817.jpg	7	0	100	0	SE
16:40	DSCN0818.jpg	5	2	71.4285714	28.5714286	NC
16:50	DSCN0831.jpg	19	1	95	5	SC
16:50	DSCN0832.jpg	5	2	71.4285714	28.5714286	NW
16:50	DSCN0833.jpg	5	2	71.4285714	28.5714286	NE
16:50	DSCN0834.jpg	9	2	81.8181818	18.1818182	CW
16:50	DSCN0835.jpg	7	1	87.5	12.5	CE
16:50	DSCN0836.jpg	7	2	77.7777778	22.2222222	SW
16:51	DSCN0837.jpg	11	2	84.6153846	15.3846154	SE
16:51	DSCN0838.jpg	9	3	75	25	NC
16:59	DSCN0845.jpg	18	0	100	0	SC
16:59	DSCN0846.jpg	5	0	100	0	NW
16:59	DSCN0847.jpg	4	4	50	50	NE
17:00	DSCN0848.jpg	13	0	100	0	CW
17:00	DSCN0849.jpg	3	2	60	40	CE

17:00	DSCN0850.jpg	6	2	75	25	SW
17:00	DSCN0851.jpg	14	2	87.5	12.5	SE
17:00	DSCN0852.jpg	15	1	93.75	6.25	NC
13:37	DSCN0882.jpg	17	0	100	0	SC
13:37	DSCN0883.jpg	4	0	100	0	NW
13:37	DSCN0884.jpg	5	1	83.3333333	16.6666667	NE
13:37	DSCN0885.jpg	8	3	72.7272727	27.2727273	CW
13:37	DSCN0886.jpg	5	3	62.5	37.5	CE
13:37	DSCN0888.jpg	5	1	83.3333333	16.6666667	SW
13:38	DSCN0889.jpg	9	4	69.2307692	30.7692308	SE
13:38	DSCN0890.jpg	10	2	83.3333333	16.6666667	NC
13:38	DSCN0891.jpg	8	0	100	0	SW
17:08	PA290073.jpg	7	2	77.7777778	22.2222222	SC
17:10	PA290078.jpg	1	7	12.5	87.5	CE
17:10	PA290079.jpg	3	2	60	40	SW
17:10	PA290080.jpg	7	2	77.7777778	22.2222222	NE
17:10	PA290081.jpg	7	5	58.3333333	41.6666667	SE
17:10	PA290082.jpg	7	4	63.6363636	36.3636364	NC

9.9 Piazza San Marco Pedestrian Count Data

Date	Picture ID	Time Block	Time	Focal Area	Pedestrians in Picture
31-Oct	DSCN0960	10:00	10:09	A	72
31-Oct	DSCN0961	10:00	10:10	B	130
31-Oct	DSCN0962	10:00	10:10	C	138
31-Oct	DSCN0963	10:00	10:11	D	34
31-Oct	DSCN0964	10:00	10:11	E	66
31-Oct	DSCN0965	10:00	10:11	F	30
31-Oct	DSCN0966	10:00	10:12	G	3
31-Oct	DSCN0967	10:00	10:12	H	257
31-Oct	DSC01865	10:00	10:01	I	196
31-Oct	DSCN0972	10:20	10:19	A	66
31-Oct	DSCN0973	10:20	10:19	B	192
31-Oct	DSCN0974	10:20	10:19	C	42
31-Oct	DSCN0975	10:20	10:20	D	31
31-Oct	DSCN0976	10:20	10:20	E	53
31-Oct	DSCN0977	10:20	10:20	F	69
31-Oct	DSCN0978	10:20	10:21	G	4
31-Oct	DSCN0979	10:20	10:21	H	207
31-Oct	*	10:20	*	I	*
31-Oct	DSCN0993	10:40	10:39	A	64
31-Oct	DSCN0994	10:40	10:39	B	118
31-Oct	DSCN0995	10:40	10:40	C	88
31-Oct	DSCN0996	10:40	10:40	D	32
31-Oct	DSCN0997	10:40	10:41	E	60
31-Oct	DSCN0998	10:40	10:41	F	70
31-Oct	DSCN0999	10:40	10:41	G	76
31-Oct	DSCN1000	10:40	10:42	H	281
31-Oct	*	10:40	*	I	
31-Oct	DSCN1013	11:00	10:58	A	97
31-Oct	DSCN1014	11:00	10:58	B	155
31-Oct	DSCN1015	11:00	10:59	C	118
31-Oct	DSCN1016	11:00	10:59	D	89
31-Oct	DSCN1017	11:00	11:00	E	121
31-Oct	DSCN1018	11:00	11:00	F	162
31-Oct	DSCN1019	11:00	11:01	G	30
31-Oct	DSCN1020	11:00	11:01	H	325
31-Oct	*	11:00	*	I	*
31-Oct	DSCN1039	11:20	11:20	A	117
31-Oct	DSCN1040	11:20	11:21	B	146

31-Oct	DSCN1041	11:20	11:21	C	95
31-Oct	DSCN1042	11:20	11:22	D	76
31-Oct	DSCN1043	11:20	11:22	E	95
31-Oct	DSCN1044	11:20	11:22	F	74
31-Oct	DSCN1045	11:20	11:23	G	14
31-Oct	DSCN1046	11:20	11:23	H	313
31-Oct	*	11:20	*	I	*
31-Oct	DSCN1065	11:40	11:41	A	97
31-Oct	DSCN1066	11:40	11:42	B	175
31-Oct	DSCN1067	11:40	11:42	C	123
31-Oct	DSCN1068	11:40	11:43	D	117
31-Oct	DSCN1069	11:40	11:43	E	113
31-Oct	DSCN1070	11:40	11:43	F	197
31-Oct	DSCN1071	11:40	11:44	G	31
31-Oct	DSCN1072	11:40	11:44	H	333
31-Oct	*	11:40	*	I	*
31-Oct	DSCN1091	12:00	12:01	A	111
31-Oct	DSCN1092	12:00	12:02	B	143
31-Oct	DSCN1093	12:00	12:02	C	102
31-Oct	DSCN1094	12:00	12:03	D	99
31-Oct	DSCN1095	12:00	12:03	E	78
31-Oct	DSCN1096	12:00	12:04	F	105
31-Oct	DSCN1097	12:00	12:04	G	30
31-Oct	DSCN1098	12:00	12:04	H	387
31-Oct	*	12:00	*	I	*
31-Oct	DSCN1118	12:20	12:22	A	93
31-Oct	DSCN1119	12:20	12:22	B	119
31-Oct	DSCN1120	12:20	12:23	C	89
31-Oct	DSCN1121	12:20	12:23	D	97
31-Oct	DSCN1122	12:20	12:23	E	102
31-Oct	DSCN1123	12:20	12:24	F	77
31-Oct	DSCN1124	12:20	12:24	G	89
31-Oct	DSCN1125	12:20	12:24	H	402
31-Oct	*	12:20	*	I	*
31-Oct	DSCN1138	12:40	12:41	A	113
31-Oct	DSCN1139	12:40	12:41	B	113
31-Oct	DSCN1140	12:40	12:42	C	96
31-Oct	DSCN1141	12:40	12:42	D	71
31-Oct	DSCN1142	12:40	12:42	E	53
31-Oct	DSCN1143	12:40	12:43	F	51
31-Oct	DSCN1144	12:40	12:43	G	39

31-Oct	DSCN1145	12:40	12:44	H	288
31-Oct	*	12:40	*	I	*
31-Oct	DSCN1158	13:00	13:02	A	100
31-Oct	DSCN1159	13:00	13:02	B	144
31-Oct	DSCN1160	13:00	13:03	C	83
31-Oct	DSCN1161	13:00	13:03	D	50
31-Oct	DSCN1162	13:00	13:04	E	66
31-Oct	DSCN1163	13:00	13:04	F	60
31-Oct	DSCN1164	13:00	13:04	G	54
31-Oct	DSCN1165	13:00	13:04	H	206
31-Oct	*	13:00	*	I	*
31-Oct	DSCN1168	13:20	13:22	A	144
31-Oct	DSCN1169	13:20	13:22	B	153
31-Oct	DSCN1170	13:20	13:23	C	113
31-Oct	DSCN1171	13:20	13:23	D	41
31-Oct	DSCN1172	13:20	13:23	E	87
31-Oct	DSCN1173	13:20	13:23	F	74
31-Oct	DSCN1174	13:20	13:24	G	72
31-Oct	DSCN1175	13:20	13:24	H	346
31-Oct	*	13:20	*	I	*
31-Oct	DSCN1178	13:40	13:42	A	133
31-Oct	DSCN1179	13:40	13:42	B	153
31-Oct	DSCN1180	13:40	13:43	C	108
31-Oct	DSCN1181	13:40	13:43	D	61
31-Oct	DSCN1182	13:40	13:43	E	64
31-Oct	DSCN1183	13:40	13:44	F	64
31-Oct	DSCN1184	13:40	13:44	G	45
31-Oct	DSCN1185	13:40	13:44	H	235
31-Oct	*	13:40	*	I	*
31-Oct	DSCN1188	14:00	14:02	A	139
31-Oct	DSCN1189	14:00	14:03	B	119
31-Oct	DSCN1190	14:00	14:03	C	72
31-Oct	DSCN1191	14:00	14:03	D	46
31-Oct	DSCN1192	14:00	14:04	E	44
31-Oct	DSCN1193	14:00	14:04	F	44
31-Oct	DSCN1194	14:00	14:04	G	37
31-Oct	DSCN1195	14:00	14:04	H	239
31-Oct	*	14:00	*	I	*
31-Oct	DSCN1198	14:20	14:22	A	101
31-Oct	DSCN1199	14:20	14:23	B	57
31-Oct	DSCN1200	14:20	14:23	C	79

31-Oct	DSCN1201	14:20	14:24	D	40
31-Oct	DSCN1202	14:20	14:24	E	40
31-Oct	DSCN1203	14:20	14:24	F	49
31-Oct	DSCN1204	14:20	14:25	G	42
31-Oct	DSCN1205	14:20	14:25	H	263
31-Oct	*	14:20	*	I	*
31-Oct	DSCN1208	14:40	14:42	A	120
31-Oct	DSCN1209	14:40	14:42	B	128
31-Oct	DSCN1210	14:40	14:43	C	94
31-Oct	DSCN1211	14:40	14:43	D	50
31-Oct	DSCN1212	14:40	14:44	E	33
31-Oct	DSCN1213	14:40	14:44	F	38
31-Oct	DSCN1214	14:40	14:44	G	21
31-Oct	DSCN1215	14:40	14:45	H	328
31-Oct	*	14:40	*	I	*

9.10 Tourist and Venetian Video Count Data

Going							Coming						
Tourist	Venetian	Stroller	Sm. cart	Lg. cart	Suitcase	Personal	Tourist	Venetian	Stroller	Sm. cart	Lg. cart	Suitcase	Personal
11	97	0	0	0	1	0	13	52	0	1	0	1	0
4	2	0	0	0	0	0	5	19	0	0	0	0	1
20	27	0	0	1	0	1	8	13	0	0	0	0	0
25	23	2	0	1	0	2	48	27	0	1	1	10	1
35	20	0	0	1	1	0	59	41	1	1	1	2	3
56	7	0	0	0	6	2	38	11	0	0	0	0	1
41	53		1	1	2		31	18		1	1		1
88	43	2		2	1	1	69	50		1	2	2	
47	44	0	0	2	2	0	27	20	0	1	1	1	0
191	24	0	0	0	1	0	173	17	0	0	0	0	0
18	35	1	0	0	1	1	21	70	0	0	0	1	0
110	36	0	0	4	3	2	108	40	2	0	1	0	1
21	38	0	1	0	0	1	36	44	0	1	0	0	0

	19												
49	22	0	0	1	0	0	60	43	0	0	0	1	1
9	13	0	0	2	0	1	19	18	0	1	1	0	1