Mobility On Venetian Expressways:

Alleviating congestion and improving navigation in Venice

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Authorship

Each member of the team contributed equally to the development of the report with each member focusing on the following in revision:

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Aaron Pepin on Results and Analysis of Manual Counting and the Rialto Island Case Study.

Rigen Mehilli on the Methodology and the Results and Analysis of the mobile application.

Taylor Flaxington on the Introduction and the Results and Analysis and the Conclusions and Recommendations of Automatic Counting.

The writing and editing of the Abstract and Executive Summaries were a collaborative effort including all members.

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Abstract

Venetians' quality of life is being affected through street congestion and safety risks introduced by increasing tourism. The team digitally modeled the streets of Venice and conducted manual and automatic pedestrian counts to learn about chokepoints and pedestrian flow across the city. The team concluded that manual counting was inefficient and inadequate while automatic counting showed potential to be used in a predictive pedestrian model.

Executive Summary

Venice is made up of 126 islands, 470 bridges, and 150 canals.[1] Venice is a walking city. Streets are sometimes as narrow as the arm span of an average adult, which is hardly enough room for fluid mobility.[2] Millions of tourists visit Venice each year, and during the summer there can be four times as many tourists as Venetians in the city.[3]The combination of large tourist crowds and their slow navigation, creates congestion and potential safety concerns.

Current efforts to manage pedestrian traffic in Venice include the use of directional signs and mobile applications. Directional signs are located at key intersections and provide guidance by pointing people toward major tourist destinations. There are also mobile applications focused on navigation that have been developed for pedestrians by large companies such as Google and independent developers including the Venice Project Center. Many of these applications focus on turn by turn navigation guided by GPS, which can be unreliable in the narrow streets of Venice.

One important tool for understanding mobility is a predictive pedestrian model, which could be used by the city to analyze current and future congestion throughout the city. The model would categorize pedestrians as two different types of agents, Venetians and tourists. This distinction is important since they move through the city very differently, Venetians moving from home to places of employment, schools, and tourists start at hotels and move to various points of interest. Such a model would need to draw on data such as attendance at major museums, pedestrian counts, and an updated graph of the streets throughout Venice to properly simulate the movement of pedestrians through the city. A prior model was created by the VPC, but needed updating and expanding. The existing street graph was updated by the team to be properly divided into individual street segments. Pedestrian counts could also be collected at various bridges throughout the city, working as checkpoints in the model. These checkpoints would be able to be sure that pedestrians are moving through the proper arteries throughout the day based on hourly data collected.

The end goal of the model is to supply it with enough data to accurately predict future circumstances and congestion. The model would alert the city about the most crowded times of the year, the most congested locations on a daily basis. This would allow for more precautionary measures to be taken in order to improve mobility and maintain a degree of safety for all pedestrians. In order to achieve this, the team developed the following mission statement and objectives:

Assist with the management of growing tourist crowds by automating the collection of data, predicting pedestrian movement year-round, and facilitating navigation of tourists through a mobile application.

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[1] Amilcar, 2015
[2] Bing, 2015
[3] Collins, 2015

Objective 1: Explore the use of automatic pedestrian counting methods.

Objective 2: Develop a framework and tools for a predictive pedestrian model.

Objective 3: Design a mobile application to facilitate navigation.

To understand the kind of data needed for accurate modeling and prediction, we first replicated pedestrian counts that had been previously completed on three bridges within the city. Researchers from the 2013 team had used counts from one day on these bridges to predict the growing number of Venetians and Tourists bi-annually through the year 2055. In working to corroborate these predictions, the team determined that the 2013 team's predictions for 2015 were significantly off. This comparison allowed the team to determined such small sample sizes of data are not representative enough to provide accurate predictions. An accurate model would depend on continuous pedestrian counts across the city, a labor intensive process. The team therefore decided to evaluate the use of automated, camera-based counting methods.

Another method the team used to understand pedestrian flow was a full day case study of the Rialto island. The Rialto island was chosen for its centralized location, number of entry points, and tourist popularity. Traffic in and out of the Rialto island at 7 bridges and two boat stops was recorded. Over the course of 12 hours on Saturday, November 21st, 2015, a total of 138,910 non-unique pedestrians passed through these entry points. 76% of the pedestrian flow was concentrated into four main bridges with peak flow occurring at 12:00 and 16:00. This data was collected to further the team's understanding of pedestrian movement and as an input for a future predictive model.

To test the feasibility of a new method of automatic counting, the team partnered with a company based out of New York, USA called Placemeter. Working with Placemeter, the team was loaned ten wireless cameras and free academic use of their pedestrian counting software. The team set up these cameras at ten locations throughout Venice and conducted manual verification counts to check their accuracy. Only three of the nine cameras installed were consistently accurate within a 15% margin of error. While there were a variety of problems with accuracy identified by the team, the major sources of error were due to poor WiFi connections and improper camera angle.

In addition to the 10 wireless cameras loaned to the team by placemeter, feeds from three existing security cameras in Venice were connected to the same software. These cameras were hardwired instead of wireless, allowing the team to isolate the variable of WiFi from the analysis of the systems. This led to more accurate counts, however, the team did not have the time to analyze the data fully. Using the total of 12 cameras available to them, the team concluded that the system for automatic counting is feasible for collecting continuous data. However, the new system still contains unidentified sources of error and should be studied further. While manual counting is consistently accurate, automatic counting methods have the potential for continuous data collection.

Our third objective was to develop a possible navigational application. The creation of the artistic concept of a mobile application focused on directional guidance, similar to signs posted by the city. This application would provide current location identification through GPS, and would be able to analyze photos of the user's current location to determine GPS coordinates. The application could then provide directional guidance to popular tourist destinations.

The team recommends all data collected and analysis performed be put toward the development of an agent-based, predictive pedestrian mobility model. The model could be used by the city to not only understand the current situation in the city, but to implement precautionary measures to manage the increasing congestion before it occurs.

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1 Introduction

Mobility and access are critical issues in daily life, particularly in urban environments. Overcrowded motor and pedestrian ways are a topic of great concern in all modern cities, but particularly in older cities that were not designed for modern modes of transportation and growing global populations. When there are too many people on the roads, problems start to arise. Factors that contribute to traffic jams include accidents, influx of people, poor visibility, unmarked or unclear routes, poor navigation systems and most importantly road size. Congestion is a current and daily problem all over the world. People spend on average 35 hours per week in traffic in Europe, which totals to 75 days or 20% of the year.[4] To combat growing vehicular traffic concerns most cities deploy tactics such as public transportation with busses, trains, subways, walking and bike paths providing alternative ways for people to move through the city. However unique issues and circumstances arise for cities that do not face vehicular traffic, but rather pedestrian traffic.

The city of Venice, Italy has to combat its own special case of congestion and traffic. Narrow streets and bottlenecks created by bridges, combined with an endless stream of tourists further complicate the mobility issue. Venice is a city like no other because there are no cars, bikes or trains within the city. The only available forms of transportation are pedestrian walkways and boats. The total length of these streets is four times the size of the Boston Marathon, in total, around 105 miles.[5] However, with tens of thousands of other people also in streets roughly half a meter (2 feet) wide, movement through the streets becomes impossible.

While many factors contribute to the growing problem of mobility on the streets, one of the largest factors is the continuous high volume of tourists. Tourists and Venetians move through the city very differently. When Venetians move through the city, they are focused, going to work, the supermarket or home. Tourists walk slowly and stop to take pictures in the middle of walkways trying to see as many sights as possible. Tourists do not understand the maze that makes up the streets of Venice. To combat the confusion and congestion, the city has put up directional signs. These signs point people in the direction of major tourist destinations and services, however, the streets in Venice are still permanently crowded. While modern cities often have the opportunity to expand sidewalks, add lanes to roads, and increase the geographical footprint of the city, Venice's framework is restricted by ever rising seas and the antiquity of its infrastructure.

Over the last 25 years, the Worcester Polytechnic Institute (WPI) and Venice Project Center (VPC) have also made significant contributions to understanding Venice's perpetual mobility dilemma. The VPC has worked on alleviating congestion by observing pedestrian behavior in the floating city. Efforts have been made to create an autonomous pedestrian model that would predict the movement of both tourists and Venetians; however, the data needed for this model is constantly out of date and does not incorporate the entire city of Venice. The method used for data collection has traditionally been manual counting, which is inevitably subject to human

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[4] Rodrigue, 2015
[5] Bing, 2013

error. The need to capture congestion on a broader scale required the introduction of a new method of counting.

This project worked towards filling the gaps of the data collected by past researchers. To fill those gaps the team counted pedestrians at over twenty different locations throughout the city of Venice. Through the use of automatic counting devices the team investigated the means to continue data collection year round. These goals are summarized in the group's mission statement:

Assist with the management of growing tourist crowds by automating the collection of data, predicting pedestrian movement year-round, and facilitating navigation of tourists through a mobile application.

To do so, the team set these objectives:

Objective 1: Explore the use of automatic pedestrian counting methods.

Objective 2: Develop a framework and tools for a predictive pedestrian model.

Objective 3: Design a mobile application to facilitate navigation.

2 Background

Since its founding in 421 C.E[6], the historic city of Venice, which was built in a lagoon, has grown to occupy more than 126 islands which are connected by over 150 canals and over 470 bridges.[7] Due to the space constraints associated with being surrounded by water, canals and pedestrian walkways are the only means of mobility within the city.

While its system of canals and walkways may have once provided adequate transportation for Venice, they are no longer sufficient to comfortably handle the volume of people and goods which move about the city. Venice now attracts more visitors than ever, with millions of people flooding its narrow walkways each year.[8] The inevitable consequences of this overcrowding are the extensive congestion of the city's bridges and streets.[9] These problems slow down almost all transportation in the city and produce hindrances for tourists and Venetians alike.

2.1 Venetian Infrastructure

The limited infrastructure of Venice must be understood in order to travel within it. Venice has been occupied for over 1500 years and was built for a different age.[10] An age of horses and walking, a time much different than today. Its 126 islands constitute an archipelago, a chain of islands strung together.[11] The islands of Venice can be seen in Figure 1.

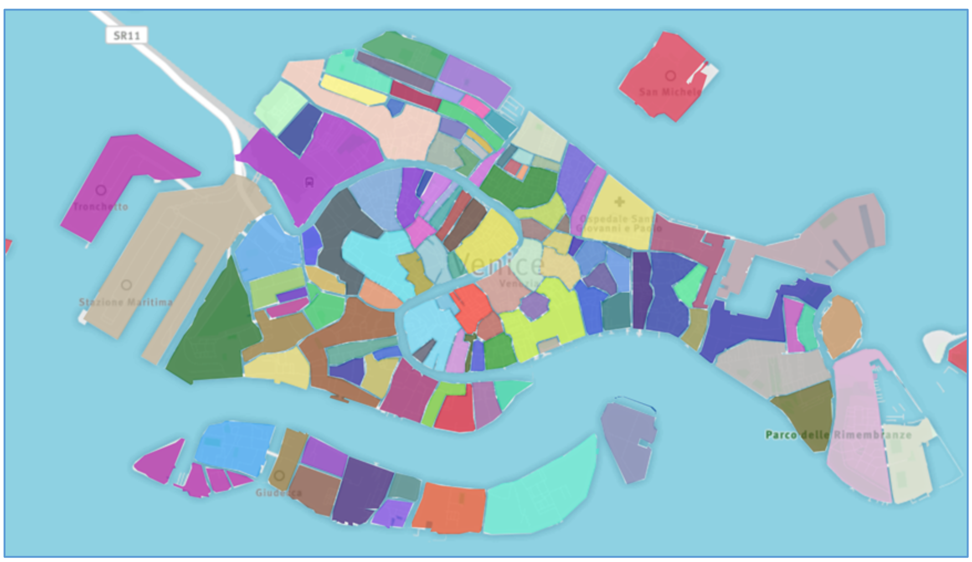

Figure 1: The 126 intercity islands distinguished by color

[6] Amilcar, 2010
[7] Norwich, 1989
[8] Collins, 2007
[9] Mack, 2012
[10] Amilcar, 2010
[11] Bing, 2010

Because the city was built in a lagoon there are only a few methods of entry into Venice. Visitors can arrive in Venice by train, bus, cruise ship, car, or by *vaporetto, a* ferry boat from the mainland city of *Mestre*. The *Azienda del Consorzio Trasporti Veneziano* (ACTV) and Alilaguna are the companies responsible for public transportation through the central canals and from the mainland to the city of Venice.[12] People arriving by train or car must use the *Via della Liberta,* which is the only bridge connecting Venice to the mainland[13]

The islands of Venice are separated by over 150 canals.[14] The canals are mostly used for the movement of goods, but some, like the Grand Canal are also used for public transportation. The Grand Canal is the largest canal in Venice and acts as the main artery for transportation of people and goods between the islands. This ‘S’ shaped canal is the widest and the deepest in the city. The Grand Canal is two and a half miles long and, at its widest point, spans 300 feet across.[15] The canals of Venice are highlighted in Figure 2.

Figure 2: Each of the 150 canals highlighted in blue

The canals are spanned by 470 bridges.[16] These bridges are often small and arc steeply so that boats traveling on the canals can pass under them. Because of this, they have many stairs. Certain bridges, which lie along main routes, are particularly important to Venice because they allow high volumes of people and goods to cross between islands. An excellent example is the Rialto, the largest bridge across the Grand Canal, which is so important to the city it has become a tourist attraction in its own right.[17] The bridges of Venice are highlighted red in Figure 3.

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[12] Durant, 2015
[13] Italy Heaven, 2015
[14] Norwich, 1989
[15] Drazen, 2015
[16] Drazen, 2015
[17] Drazen, 2015

Figure 3: Each of the 470 bridges highlighted in red

The bridges of Venice are connected by an intricate network of streets which weave their way throughout the islands of the city. These streets are often narrow, averaging between three and ten meters but some are less than one meter wide.[18] The unplanned nature of the city introduces complications like winding and dead end streets. Streets which run across several islands tend to be main drags and draw heavy traffic. The maze of Venetian streets can be seen outlined below in Figure 4.

Figure 4: The 2,650 streets of Venice highlighted in yellow

[18] Amilcar, 2015

2.2 Pedestrian Movement in Venice

In order to understand the problem of pedestrian mobility in the streets of Venice, it is important to consider how people move throughout the city. Boating and walking are the main forms of transportation throughout the city.

2.2.1 Navigating the canals

The main public boat line, ACTV, operates much like a public bus system would in any other city. There are 15 established routes that the boats follow throughout the day.[19] The routes are shown below in Figure 5, and the ACTV's waterbuses in Figure 6.

Figure 5: The published routes of the ACTV public transportation system

[19] ACTV, 2015

Figure 6: Waterbuses used by the ACTV public transportation service

Another source of public transportation are the *Traghetti*. *Traghetti* are gondola-style boats which ferry passengers back and forth across the Grand Canal. They are fairly inexpensive, usually costing about two euros for tourists and seventy cents for Venetians, but they only carry a small number of people at a time.[20]

Water taxis are also a potential form of transportation however they are more expensive than public transportation. Private boats are the final form of transportation but are used more for the transportation of goods rather than pedestrian movement.[21] Because of pollution, swimming in the canals is unsafe and frowned upon.

2.2.2 Navigating the Streets

Walking is the only alternative to boating within Venice. Other forms of transportation, such as bicycles, are illegal as well as impractical.

The most common method of navigation is an innate understanding of your location based on past experience. One navigational aid which comes with experience is an understanding of the sestieri, or neighborhoods in Venice. The six sestieri of Venice are: *Cannaregio, S. Croce, S. Polo, San Marco, Dorsoduro,* and *Castello.* It is important to understand these *sestieri,* because many streets throughout the city have the same name and locations can only be clarified by neighborhood. Unfortunately, gaining an innate understanding of the city takes time and cannot normally be gained by tourists or short term visitors.

If someone moving in Venice does not have an extensive understanding of the city they have to rely on a small number of navigational aids available to them. The most common navigational aids are digital and physical maps which people can use to locate themselves and the direction of their destination based on addresses, public squares, and monuments. Physical maps are

[20] Imboden, 2015
[21] Imboden, 2015

often provided to visitors by hotels and come with the city's major attractions starred. Digital maps are also readily found online at sites such as google maps and they can be accessed through a variety of mobile applications. These technologies often include GPS to ease a traveler's navigational experience. An image of tourists using traditional maps can be seen in Figure 7.

Figure 7: Tourists using paper maps to navigate through the city

Another tool available to tourists is a series of yellow signs posted by the city which direct people toward major tourist destinations. They are placed above the first floor of buildings so that they are easily seen and located along major streets throughout the city. They display the name of a popular tourist destination nearby with an arrow pointing in its direction. An example yellow sign can be seen in Figure 8.

Figure 8: Nizioletto (white sign) providing street name and yellow signs on the left providing directional guidance

The last method of navigation is asking locals for directions. It is often used by travelers who are in areas without yellow signs, are looking for less common destinations, or are unable to acquire or read a map. This is a comparatively uncommon method because it is less reliable than those previously discussed. Asking for directions often has mixed results as language barriers, confusion about the destination, and lack of general knowledge can limit its usefulness.

2.2.3 Obstacles to Pedestrian Movement

There are many obstacles throughout the city of Venice which slow pedestrian traffic and are the source of significant congestion throughout the city. These obstacles include pull carts transporting goods, businesses which use the street, stairs on bridges, and consistent flooding.

Many hand carts move throughout Venice as people use them to transport items which could not be moved by boat. These carts create an obstacle for pedestrian traffic because they take up large amounts of space on the road. They are often heavily loaded and tend to move slowly. This is especially noticeable when they must go up and down stairs as the carts are designed to travel one step at a time. Images showing hand carts moving throughout Venice can be seen in Figure 9.

Figure 9: Cargo deliveries through the streets creating congestion

Restaurants with outdoor seating and shops both contribute to congestion in Venice by blocking pathways throughout the city. Many restaurants in Venice have a sizable amount of outdoor seating. The consequences of outdoor seating are important given the narrow streets in the city. Large or small tables, a plethora of chairs, and waiters delivering plates can create bottlenecks even on the wider streets. This might be ideal for shops who benefit from visitors walking at a slow pace and having time to be drawn in by souvenirs and other Venetian goods. However, the slow moving tourists also clog the streets and are hard for more hurried pedestrians to maneuver around. On any of the streets where these outdoor impedances are located delays are added to the commute time of any local, seen in Figure 10.

Figure 10: Outdoor seating located outside of a restaurant

The 470 bridges in Venice can also cause bottlenecks and traffic jams. The likelihood of congestion to build up around a bridge is determined by several factors such as bridge location, width, and number and incline of its stairs. Bridges in central locations are likely to become overcrowded due to a high volume of pedestrian traffic. Some bridges, like the *L'Anconeta* are not wide enough to handle the loads of people who want to use them which also creates build up. Stairs create congestion as they take more time for people to cross. This is especially true for people who are carrying luggage, moving cargo, and the physically impaired. Each of these factors make bridges a likely place for bottlenecking to occur.

The problem of transportation is worsened during *Acqua Alta*, floods of over 100 centimeters which occur in Venice throughout the year. When flood waters are 100 centimeters above the standard measurement line at *Punta della Salute* near *San Marco* Square four percent of Venice is flooded. When the tide waters reach over 140 centimeters, over 90 percent of the city is flooded.[22] In reaction to this flooding, the city of Venice puts up raised walkways so that pedestrians are not walking in the water.

2.2.4 Tourists create congestion

Pedestrians themselves are a significant source of congestion in Venice. The tendency of tourists to spend large amounts of time walking through the city makes them particularly problematic when it comes to congestion in Venice. Additionally, Venice experiences overwhelmingly large tourist populations.[23] Tourists are particularly problematic for Venice because they travel more slowly than locals or commuters.

One of the main reasons tourists move more slowly than locals is their tendency to stop frequently. As tourists move through a city, especially a city of art and architecture like Venice, they are constantly on the lookout for attractions for which they will stop. These attractions could

[22] Bing, 2013
[23] Actv SpA, 2015

be a pretty view, church or store. Stopping does not bother tourists as they are generally on vacation and not in a hurry. Searching for things to look at causes tourists to move slower than they normally would, because they are focused on the world around them instead of the path ahead. Both of these actions delay tourists enormously while they travel. Tourists stopping on a crowded bridge to take a picture can be seen in Figure 11. [24]

Figure 11: Tourists stopping to take pictures at popular destinations such as the Accademia bridge shown above

Poor navigation slows tourists while they walk and increases the amount of time they spend in the streets. While someone is lost, especially in a new place they greatly slow their speed. This gives them more time to look for information in their surroundings, such as a street sign or familiar store, which might indicate their location. Being lost greatly increases the total time tourists spend in the streets because they spend time wandering instead of heading toward their destination. If they become truly lost, they could be forced to design an entirely new route.

Tourists tend to move in groups. These groups range widely in size from couples to full tour groups of 20 or more. Group travel reduces movement speed because humans tend to travel more slowly in groups as they are slowed by things like conversation or the slowing of another group member. Furthermore, the desire of groups to walk adjacent to each other makes them hard to pass. Large tour groups are particularly troublesome for traffic flow as a single group of tourists can block an entire street, forcing everyone behind them to walk at a greatly reduced rate.

A limited number of common destinations also causes crowding among tourists. Within Venice the two most popular attractions are The Doges' Palace and Saint Mark's Basilica.[25] The popularity of these attractions, which are both located around Saint Mark's Square, regularly

[24] Carr, 2014
[25] Bing, 2013

causes extreme crowding throughout the entire neighborhood of *San Marco*. Figure 12 shows how overcrowded the *San Marco* area can become, the man with the red umbrella in front is leading a group of tourists.[26]

Figure 12: Large tour groups move through the city in this picture, guided by a red umbrella

In contrast to the tourists, Venetians move quickly around the city. Venetians, not being on vacation like tourists, are more goal oriented. They are attempting to reach a location like school or work at a specific time and, generally, do not plan to make stops along their way. As they have traveled paths throughout the city they are unlikely to become lost, often intentionally taking side streets to avoid crowded areas. Being locals, they have also seen most of the historic sites around them and are unlikely to visit large attractions. For these reasons Venetians contribute far less per capita to the problem of congestion in Venice than tourists.

According to an *International Business Times* article, locals claim that "tourism has hit critical mass" and is not going to decline anytime soon.[27] This attitude is explained by the Head of the Venice Project Center and Worcester Polytechnic Institute Professor Fabio Carrera in a National Geographic video about Venice.[28] He explains that, as worldwide living conditions rise, increasing numbers of people can afford to visit other countries. Millions of tourists visit Venice each year for short periods of time on their vacations. Figure 13 tracks the increase of tourism within Venice per year since 2001.[29]

[26] Cable, 2014
[27] Salo, 2015
[28] National Geographic, 2013
[29] Citta' di Venezia, 2014

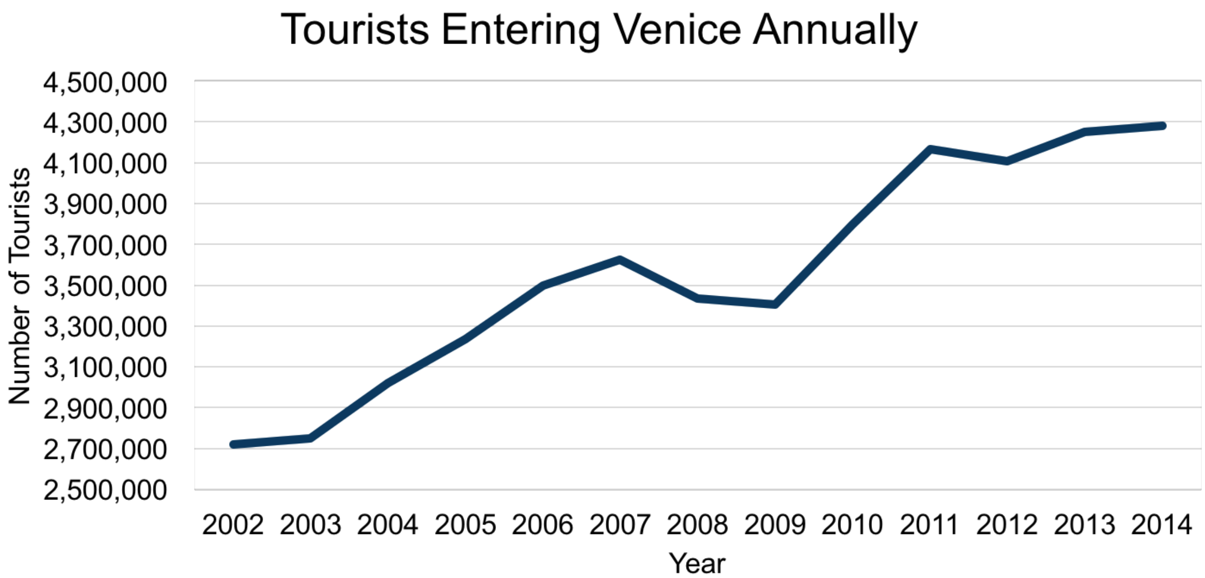

Figure 13: A graph depicting the continuing rise of the tourist population in Venice

Tourists that plan to spend only a few days in Venice often prioritize visiting many attractions in short periods of time. This means they will spend large proportions of their time in the streets. The greatest draw of tourists to Venice is *Carnevale*, a multi-day Venetian festival which occurs in February. This event primarily takes place in Saint Mark's square and attracts around 3 million tourists per year.[30] These large volumes of people easily overwhelm Venice's small spaces as seen Figure 14.

Figure 14: St Mark's Square full of pedestrians during a major event

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[30] Venipedia, 2015

2.2.5 Problems caused by Congestion

It is easy to forget that Venice is a working city in addition to a tourist attraction. Tourists are not only getting in the way of other tourists, but impeding the mobility and functionality of the working population of Venice as well. The 60,000 residents of the city who live and work there constantly have to deal with varying congestion on their daily commute created by tourists, by foot or by boat.[31] Based on the traffic of tourists or their ability to avoid larger popular areas, this congestion can greatly affect the residents of Venice.

One study completed in India explains government defined classes of pedestrian roads or pathways. It offers data on the average space needed for each person walking to travel without being blocked.[32] Some of these data are depicted in Figure 15.

Width of Footpath(m)	Capacity in number of person per hour	
	All in one direction	In both direction
1.50	1,200	800
2.00	2,400	1,600
2.50	3,600	2,400
3.00	4,800	3,200
4.00	6,000	4,000

Figure 15: Findings of a study in India relating pedestrian flow to the size of the walkway

Based on this, the researchers calculated the number of people that would be able to pass through certain size streets in an hour. For example, in a minimum street size of 1.5 meters, 1200 people per hour can move in one direction or 800 people per hour can move in two directions as seen in Figure 15. Since this is approximately the size of many streets in Venice, similar numbers can be used as a baseline while adjusting for more Venice specific norms and information. The similarities of this study to the city of Venice stem from the small street sizes and the large quantity of people on the roads at any given time.

This study also defined levels of congestion according to their Levels of Service, a grade reflecting the speed of traffic flow in a space. This flow is classified according to size of passage and number of pedestrians on a scale from A-F, where A is free moving traffic, and F is immovable congestion. If the city of Venice had LOS information about pedestrian volumes on its streets it could calculate how much congestion slows down Venetians each day.

A team working for the VPC in 2013 found that a standard route from the Rialto Bridge to the San Zaccaria boat stop took ten minutes to travel on open roads. However, once the path became congested by tourists the same trip took about 35 minutes, which is more than three times slower. The route which they timed can be seen in Figure 16.

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[31] Venipedia Demographics, 2015
[32] Singh, 2014

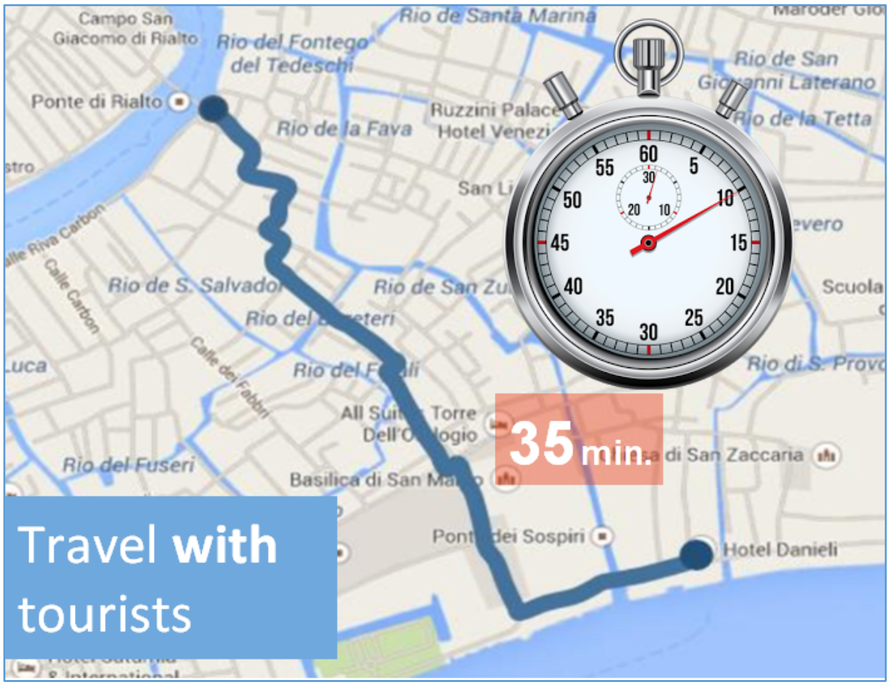

Figure 16: A sample route that can be affected by congestion created by tourists

Overcrowding is not just a hassle for commuters. Immobility in public spaces can have serious consequences. In September of 2015, over 1,200 people were killed in a stampede at the Hajj, the location of an annual Islamic pilgrimage.[33] With so many people in one confined area there only needed to be a simple shift within the group for the stampede to escalate. It is possible to imagine a similar situation occurring in Venice. The total area of city streets within Venice is only approximately 1.07 square kilometers or 0.41 square miles.[34] According to a UN census, the peak total population of Venice in 2012 was 260,060 people.[35] This means that if everyone simultaneously decided to be in the streets, each person would have 4 square millimeters of available space. In practical terms, this means that the streets of Venice cannot physically support all of the people present in peak tourist times. It was estimated that in 2014 approximately 135,146 people moved throughout Venice each day.[36] In the case of a citywide evacuation, the incredible number of people in the streets moving toward the same exits, could easily lead to trampling. There are actions that need to be taken in Venice for other tragedies like that of the Hajj to be avoided.

2.3 Management of Pedestrian Flow

The current work being done to manage pedestrian flow and ensure safety in Venice is limited. The city has implemented a range of solutions, mostly relating to signage, but they lack data on

[33] Yan, 2015
[34] Bradfford, 2013
[35] UNSD, 2015
[36] Connor, 2015

pedestrian movement required to support more substantial measures, like the proposed limits on tourist access to certain parts of the city, which have been called for by many prominent locals.[37] Clear data on pedestrian movement is critical to identifying overcrowding and choke points where congestion is consistently an issue. An understanding of overcrowding and choke points are key to effective pedestrian management and proper regulations.

2.3.1 Previous attempts to manage pedestrian congestion

Currently a number of solutions to reduce congestion have been implemented throughout the city. One prominent solution are the yellow signs which direct tourists toward main attractions and are located along main streets throughout the city. These signs help to lessen congestion by reducing the number of confused and wandering tourists. Unfortunately, signage cannot be everywhere as it would be costly to install and visually unappealing.

Mobile apps and street maps are also widely dispersed around Venice. These, like signage, are helpful in many situations as they can be used to identify location and plan routes. However, they often backfire and create more congestion as people often stop suddenly in the middle of streets to verify their location. Additionally, many GPS based applications are ineffective in Venice as GPS signals are weak throughout the city.

Other solutions to the problem of congestion in Venice have been limits on tourism. Most of these solutions focus on creating a toll for non-Venetians to enter certain parts of the city or on limiting particularly damaging tourism like cruise ship access.[38, 39] Many of these solutions are backed by powerful anti tourism campaigns like that of Venessia.com, a pro-Venice organization with tourism solutions of their own.[40] An image of Venessia.com's anti-tourist advertisements can be seen in Figure 17. One reason proposed solutions have not been accepted is because they lack scientific data like specific pedestrian volumes. Without data like a LOS for streets throughout the year details such as how many people or ships should be allowed into the city cannot be determined. Pedestrian tracking data will also be important after traffic management solutions are implemented. Understanding changes in total movement will help people understand the impact the implemented solutions have made.

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[37] Sterne, 2015
[38] Giliberto, 2015
[39] Scurati, 2015
[40] Soffiato, 2015

Figure 17: An anti-tourism advertisement

These two promising solutions to reduce pedestrian congestion, navigational apps and tourism limits, both require clear understandings of pedestrian volumes and flow. Therefore, a model of pedestrian movement within the city which accurately describes current and future movement must be created.

2.3.2 Pedestrian Modeling

Establishing a model which simulates and predicts pedestrian flow can make studying and managing traffic more efficient. A paper published by Thurstain-Goodwin details some of the most important features in the creation of a predictive pedestrian model.[41] These features often include socioeconomic and behavioral characteristics. These characteristics for pedestrians within models can impact how pedestrians are predicted to move. Pedestrians with different characteristics move differently in public spaces. Within a model of Venice pedestrians can be differentiated as either tourists or Venetians. For example, it might be predicted that an agent representing a Venetian navigates towards the industrial area of the city in order to get to work. Similarly, an agent representing a tourist might migrate to a tourist attraction or hotel. The model would then use the shortest possible distance between each point in an agent's agenda to predict their movements. Paths are based on a virtual street map, a map with virtual streets that agents move on in the model. Once an agent’s path has been determined the agent is shown as moving throughout the city at a set pace. While people always move somewhat unpredictably, by developing classes of pedestrians it is possible to create more accurate models.

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[41] Thurstain-Goodwin, 2001

In order for the model to be populated data on existing pedestrian flows must be collected. The two main methods of pedestrian data collection used around the world are Manual and Automatic pedestrian counting.[42]

2.4 Manual Pedestrian Counting

Manual counting relies on a person tallying the number of people who travel through a particular spot over a given period of time. This approach is expensive due to the large number of people required to ensure accurate, continuous counts at many locations. The number of locations that are counted must be limited and counts are often done in 15 minute spans to avoid exhausting counters.[43], [44] Therefore manual counting is often limited and can result in incomplete data collection. Figure 18 shows a person conducting a manual count.

Figure 18: A member of the team standing in front of Ponte de l'Anconeta, one of the bridges studied

One distinct advantage of manual counts is the counter's ability to determine observable demographic information such as range of age, nationality, or gender of pedestrians.[45] In *Tourist or Venetian,* Fabio Carrera discusses the challenges of determining nationality during pedestrian counts.[46] Counters' judgements about demographics, such as the distinction between tourist or Venetian, have been made by previous researchers at the VPC, who analyzed pedestrian movement at six bridges in Venice.[47]

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[42] Schneider, 2014
[43] Emmons, 1965
[44] Brofford, 2013
[45] Schneider, 2014
[46] National Geographic, 2013
[47] Brofford, 2013

2.5 Automatic Pedestrian Counting

Automatic counting typically relies on cameras, infrared sensors, lasers, or a variety of other automated tools to count pedestrians.[48] Different options have unique advantages and disadvantages, but for this project the team focused on camera based counting technologies. Figure 19 shows different styles of cameras and sensors utilized by three companies who work in this field.

Figure 19: Existing sensors that could be used for pedestrian counting

A great deal of software exists or can be modified for pedestrian counting. Software can be found through open source computer vision software, or Open CV. However, the accuracy of these Open CV programs is uncertain. Furthermore, they have not been designed to run on existing camera networks. Camera networks already exist in most major cities across the world and consist of any cameras in the city set up to monitor public spaces for security reasons. These cameras stream video or take pictures, but rarely count pedestrians. However, they are linked to a central network accessible by the municipality. Current available software and hardware solutions are offered by a variety of companies such as Placemeter, Traf-Sys, and SenSource which produce cameras and software specifically designed to count pedestrians. Only Placemeter however, has software capable of counting pedestrians from any camera stream.

After installing automatic counting cameras and software, automatic counts can be made continuously and indefinitely maintained with marginal maintenance costs. This approach leaves no gaps in pedestrian data regardless of weather conditions, time of day, or other factors which hinder manual counting.[49] Shortcomings associated with automatic counting, however, are that the cameras are unable to distinguish demographic factors like age as manual counters are able to do.[50] This is limiting when data is fed into a model which requires distinctions between types of pedestrians.

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[48] Steindel, 2008
[49] Rust, 2014
[50] Schneider, 2014

2.6 The Existing Model of Venice

There is currently one existing model of the city of Venice which has been assembled by the Venice Project Center.[51] This model is based on data that has been collected by Venice project Center Teams since about 2009 and a screenshot of it can be seen in Figure 20. This data is focused on the area around *San Marco* square and is stored in the CK Console, a database created by the VPC.

Figure 20: A screenshot of the existing pedestrian model functioning in St Mark's Square

Unfortunately, the VPC model is based on small sample sizes of data taken mostly in the months of November and December. Because of this its accuracy for predicting pedestrian movement year round is low. Furthermore, the existing model was created using an inaccurate street map so pedestrians are often shown moving over buildings or into canals rather than only on real streets. These inaccuracies are significant enough to render the existing model useless.

The VPC has also collected data for models based off pedestrian volumes predicted by a 2013 VPC team.[52] The VPC mobility team of 2013 chose six bridges for which they measured pedestrian flow. The six sites that the 2013 team studied were *Ponte delle Guglie, Ponte de l'Anconeta, Ponte de l'Ovo, Ponte dei Bareteri, Ponte de le Ostreghe,* and *Ponte della Paglia.* The 2013 team then predicted future traffic for each bridge using a formula which accounted for growing tourist populations. The 2013 VPC team hoped that their predictions would be validated by future project teams and that their predictive data could be used in future models.

These significant gaps in pedestrian data make implementing solutions to Venice's congestion problem difficult. These gaps need to be filled before solutions to the problem of congestion can be effectively implemented within the city.

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[51] Smith, 2015
[52] Brofford, 2013

3 Methodology

This project gathered and consolidated data on pedestrian movement and updated a map of the city to create the framework for a model that attempts to predict pedestrian movement of tourists and Venetians. The project mission is reflected in the 3 primary objectives:

Objective 1: Explore the use of automatic pedestrian counting methods.

Objective 2: Develop a framework and tools for a predictive pedestrian model.

Objective 3: Design a mobile application to facilitate navigation.

The project encompassed the main islands and arteries of the city of Venice. The previously mentioned objectives were accomplished by focusing on the flow of people across multiple bridges, walkways and boat stops. In order to accomplish Objective 1, the team also developed and investigated a camera-based method for continuous, automatic data collection. Although manual counting is an acceptable tool for data collection, automatic data collection was essential for this objective in order to simultaneously count multiple sites.

Both manual and automatic counts were carried out on the main islands and arteries instead of one specific area, in order to more accurately represent movement throughout the entire city. The team worked to fill any data gaps resulting from manual counts made in the past by the Venice Project Center (VPC) and then expanded the data collection to the city limits. Although the compiled data for Objective 1 can independently provide useful information on pedestrian traffic to the city, the team intended to also use this information as a tool for Objective 2.

The overarching goal and scope of this project was to contribute to a system, which has the ability to model year round pedestrian congestion of any street in the city of Venice at any time. Additionally, the team contributed to facilitating navigation through a mobile application concept, which can also be used during emergency situations, such as an evacuation.

The established time frame of this project was from October 2015 through December 2015, which includes the entirety of the team's stay in Venice.

Information regarding pedestrian movement is crucial. Being aware of the number and location of people during all hours of the day can help pedestrians distribute themselves more uniformly by avoiding congested areas and high traffic destinations. More importantly, this information can be used by the Venetian government in order to make better and more informed decisions when managing pedestrian flow. The city can investigate the trends in pedestrian movement in order to predict future congestion and take preventative measures, especially in cases of emergency.

3.1 Comparison to Manual Counts Conducted in 2013

Using an approach described in Section 2.4 Manual Pedestrian Counting, the VPC had counted the number of people crossing at seven bridges in 2013.[53] The current team repeated manual

[53] Boats and Bottlenecks, 2013

counts at the three Northernmost bridges order to validate the traffic flow predictions made in 2013. Investigating the data on congestion at these seven bridges is effective, because they connect main arteries of Venice and are good representatives of pedestrian flow in the city. The location of each bridge counted in 2013 is illustrated in the map of Figure 21.

Figure 21: Seven previously used sites for manually counting

The team used manual counts to increase the amount of pedestrian information available to the VPC. These manual counts were conducted by groups of two at three of the counting locations in Figure 21. Positioning was important, since a mental line had to be drawn in such a way that every pedestrian crossing the bridge was counted. A typical and effective position for a counter can be at the bottom of the bridge, counting people as soon as they step on or off the bridge. One group member conducted counts for incoming traffic, while the other conducted counts for outgoing traffic. Incoming traffic was defined as the direction of greater traffic flow.

Each member of the team held a clicker in each hand as a tallying device, which increased by one each time it was clicked. One clicker was used to count Venetians and the other recorded tourists. This two-person method was highly effective as it ensured counters did not become confused by looking in multiple directions. It also allowed them to focus on differentiating passersby as either tourists or Venetians. The distinction between tourists and Venetians was based on the criteria presented in Table 1.

Table 1: Distinctions used by the team while counting for Venetians versus tourists

Venetian	Tourist
Walks relatively fast or walks a dog	Looks around and points at buildings
Does not look around at buildings	Carries luggage
Generally older demographic	Carries a camera and/or map
Wears work clothes	Usually walk in groups or couples

The methodology for the three bridge counts was held consistent with the methods of the VPC counts in 2013 to ensure comparability of each group's results.

3.2 Rialto Island Case Study

Movement of people within the city of Venice is broken down to moving from island to island. In order to collect information on congestion, the team conducted a case study on the Rialto Island, aiming to reveal general trends that may also apply to neighboring islands. The full day manual count involved recording every pedestrian entering and exiting the Rialto Island from 7:00am to 7:00pm. Pedestrian counts took place at the island's bridges and boat stops as depicted in Figure 22. One bridge at the southern tip of the island was discarded due to lack of available manpower after consideration and the recommendation of local Venetian collaborator Piero Toffolo and advisor Fabio Carrera. The nine remaining entry points are shown in Figure 32, with the two ACTV boat stops represented by one dot.

Figure 22: Entry points to the island that were counted on November 21st, 2015

The team selected this specific island primarily because of its popularity and the fact that Venice's largest bridge, the Rialto Bridge, is one of the entrance points. Feasibility was also a factor, since the island included a manageable total of ten counting sites. Depicted in Figure 16, are the seven bridge sites and the two boat stops that were counted manually. The boat stops are represented together as one red circle. The team was able to reach out to the VPC and successfully recruit students willing to participate in the count. A total of 18 counters participated in this effort, with two counters for each site. The only exception was the Rialto Bridge, which required four counters due to its high volume of traffic.

It is important to clarify that the Rialto Island full day count did not distinguish between Venetians and tourists, as it primarily focused on pedestrian flow in and out of the island. The participants were instructed to follow the manual counting procedure as explained earlier in Section 3.2 Rialto Island Case Study, but instead of counting Venetians and tourists, one clicker counted pedestrians going in and the other counted pedestrians going out of the island. Every participant had a two-hour counting shift followed by a two-hour break. When the first person was on break, the second person was on a counting shift in order to ensure continuous data collection. The number of pedestrians going in and out of the island was recorded on a spreadsheet every 15 minutes by each counter.

3.3 Autonomous Counting

In order to track pedestrian movement on a larger scale and capture high congestion areas, the team automated the counting process by using cameras and counting software. Nine cameras were installed in various parts of the historic city of Venice, while the software analyzed traffic and counted people walking by. The location of each camera is depicted in the map in Figure 23:

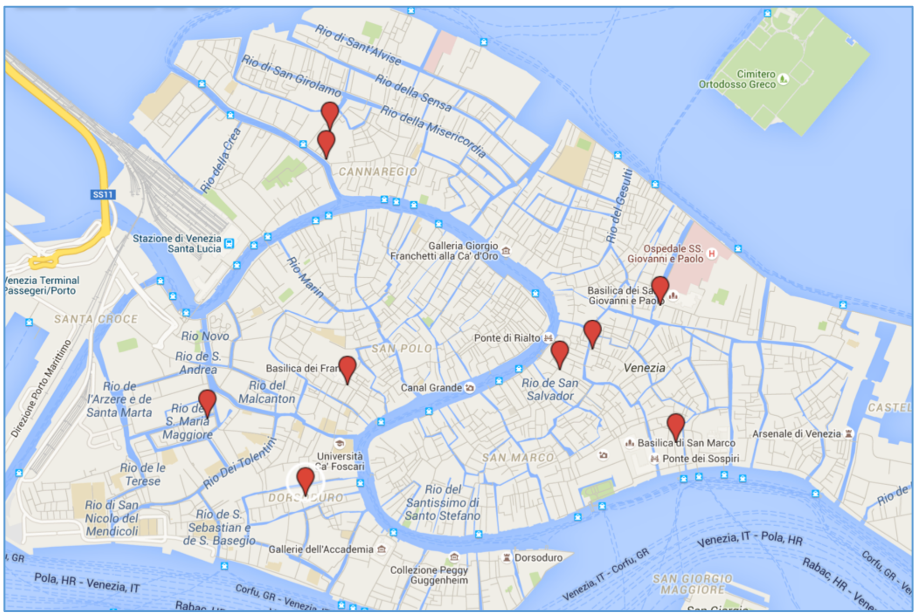

Figure 23: Nine locations at which the team installed D-Link 933L wireless cameras

One of the team's goals was to test whether cameras can reliably be used as an automatic method for counting pedestrians so future counts can be exclusively done through software. In order to achieve this goal, the team approached Placemeter, a New York based company that specializes in urban pedestrian counting. Placemeter was chosen primarily because its software was designed for public outdoor counting, which was one of the team's main objectives. The team then drafted a problem statement and application for academic use of this software. Placemeter accepted the application and partnered with the team. The proposal can be seen in Appendix A: Proposal to Placemeter for Academic Use of their Software.

The Placemeter software deciphers moving pixels in a video feed in order to analyze pedestrian traffic. The video stream input could be from existent camera feeds, but the team preferred the freedom of choosing specific locations and installing cameras accordingly. An unobstructed street viewing location, access to a power outlet, and reliable WiFi comprised the main requirements the cameras needed to function. The team worked with the VPC, specifically Piero

Toffolo, to target streets with high pedestrian volumes and to install cameras. As part of the partnership, Placemeter provided the team with 10 D-Link 933L cameras and access to its software for the duration of the project.

The D-Link cameras had to be configured before they could be used. The team powered on each camera and connected it to a laptop computer via an Ethernet cable. Once connected, the camera's Internet Protocol (IP) address was identified by running "Angry IP Scanner" software which was suggested by Placemeter. Then, by typing each IP address into an internet browser, a control panel was accessed for each camera. The website user interface and control panel is illustrated in Figure 24.

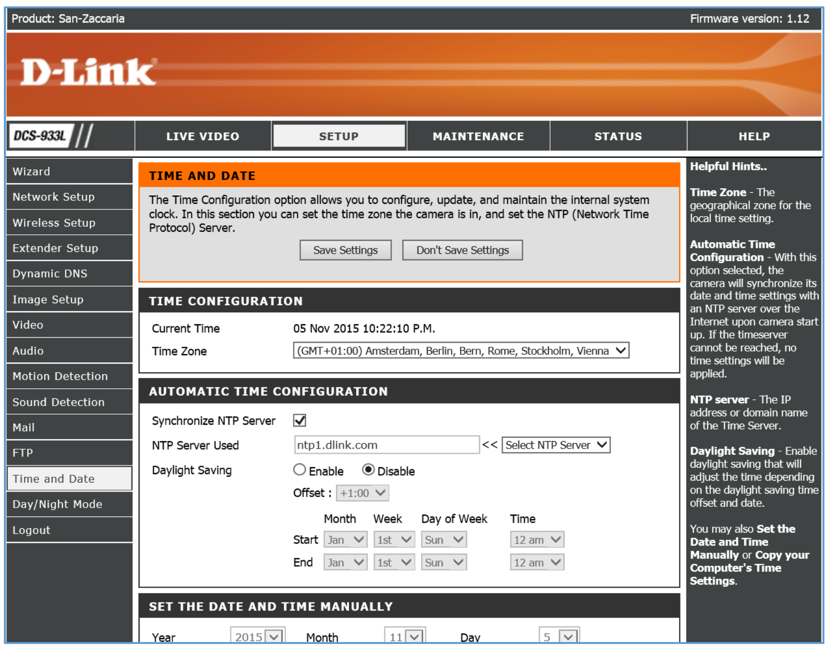

Figure 24: Online interface accessible by the team used to format the cameras

Using this control panel, the team was able to register each camera on a WiFi network and configure it in order to comply with Placemeter's software. Examples of settings changed included time and date, day mode, audio, and a path through which to send the video feed to Placemeter. Setting the cameras to always run in day mode prevents them from turning on external lights, making the cameras less obtrusive to pedestrians on the street.

Once the cameras were configured they could be installed for automatic counting. The team identified nine locations where the cameras could monitor pedestrian walkways. Ideally, cameras should be placed approximately ten feet off the ground with an unobstructed, bird's-eye view of the walkway being monitored. However, depending on the building and the location, some deviations in height and angle were acceptable and necessary for camera placement. A map with the camera locations can be found in Figure 23.

Placemeter drew measurement points for the camera's view show a visual here of this and gave feedback on whether or not the camera was properly configured. Once the video live feed was approved by Placemeter's quality assurance personnel, the team activated it through the Placemeter dashboard and it began collecting data.

The team was also able to contact VENezia Informatica e Sistemi (VENIS SpA), which is a company that liaisons with the municipality police in order to maintain a security camera network for crime prosecution. These cameras were important because coupling the counting system with the existing camera networks would yield the greatest amount of data. Additionally, it wouldn't require any additional setup or construction by the city. The team held a meeting with company representatives and was granted the option of selecting three camera streams from the company's network in order to test them. The locations of these cameras as shown in Figure 25.

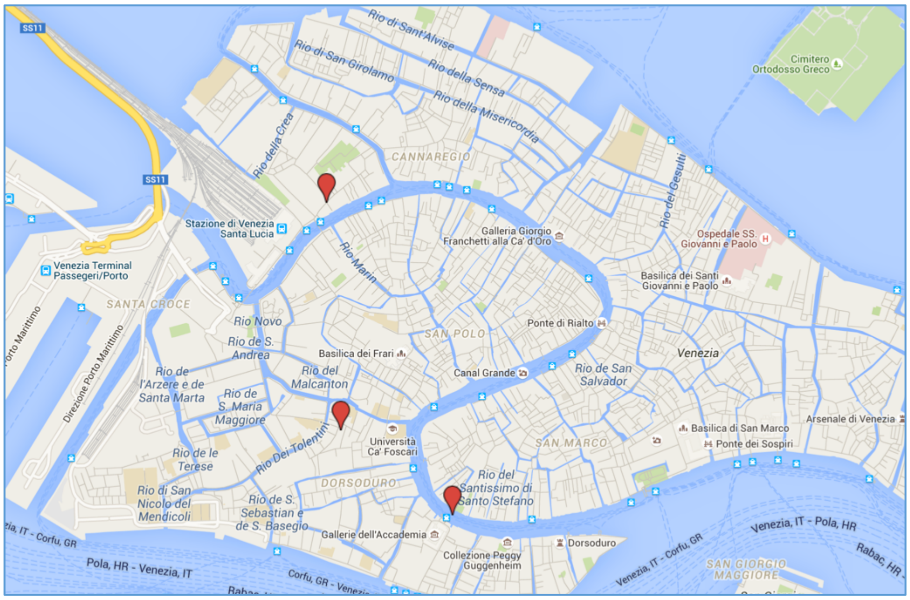

Figure 25: Locations where the team was granted access to streams from cameras maintained by the City of Venice

After the video feeds were being counted by Placemeter, the team performed manual counts in order to validate the results being produced by the cameras. In order to do this, team members stood outside at the location where the line was drawn in the feed and used manual clickers to count pedestrians passing each way. Over fifty hours were spent validating the Placemeter and city cameras. Verification counts will take up the time and manpower of future users of this system. At least two hours of validation counts were performed at each camera. Aside from verification counts, daily emails were sent to the company Placemeter to make sure tasks were completed.

3.3.2 Placemeter Data Visualization

In order to analyze traffic, the software conducts head counts to monitor the number of pedestrians crossing pre-determined lines, called measurement points, from a video feed. After determining the number of pedestrians who pass through an area, Placemeter can return the information as an Excel document or line graph. The Excel spreadsheet showed the number of pedestrians moving in each direction per hour. For better visualization, the Placemeter dashboard contains a graph of hourly pedestrian totals for each measurement point as illustrated in Figure 24.

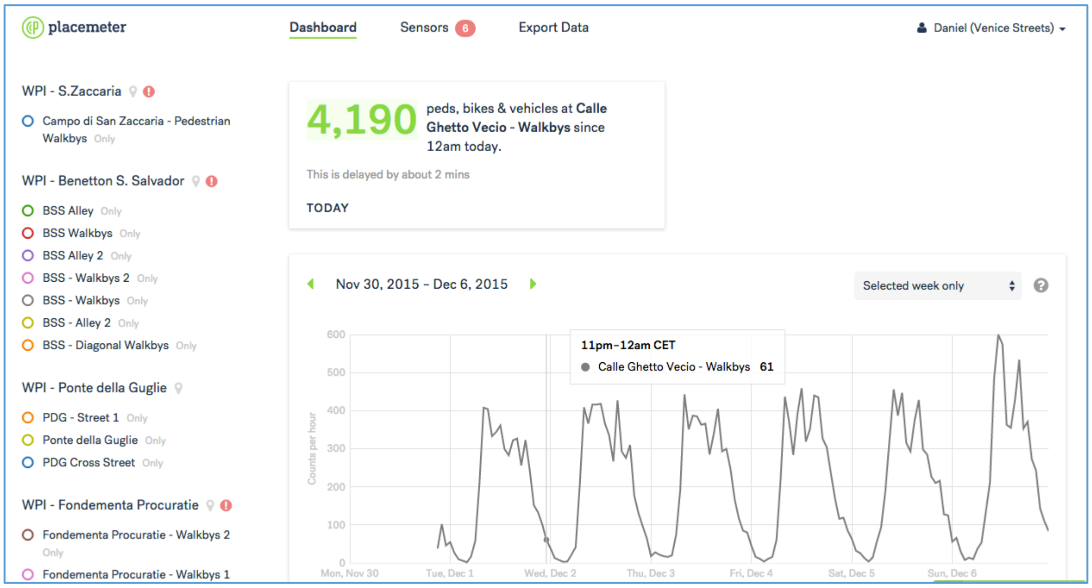

Figure 26: A screenshot of the online Placemeter user interface

The graph was updated each hour allowing data to be viewed in almost real time. At the end of the project all collected data was given to the VPC for use in the autonomous pedestrian model.

In order to verify the data of each automatic counter, the team visited each camera location at sample times and conducted manual counts for pedestrians crossing the measurement line overseen by the camera. Manual verification counts of the automatic counters were taken in one hour blocks to match the timeframe of the Placemeter software. If the automatic pedestrian count was within 5% of the manual count for the same hour, the data was deemed acceptable and added to the team's counts of pedestrians across the city. When an autonomous count was not deemed acceptable, Placemeter was contacted to identify and fix the problem.

3.4 Destination Site Counting

While in Venice the team was able to obtain the Annual Tourism Report published by the city. This report details different aspects of tourism in Venice during the year. Within this document there is information published specifically on museum attendance. The team obtained the number of people that attended each museum annually, as well as monthly, during 2014 directly from the report and documented it in a spreadsheet. The museums, for which information was collected, include: The *Palazzo Ducale, Museo Correr, Museo del Vetro, Ca' Rezzonico, Ca'Pesaro, Museo di Storia Naturale, Palazzo Mocenigo, Casa di Carlo Goldoni, Torre dell'Orologio, and Museo del Merletto*. These data were gathered to help determine possible congestion points in the future.

3.5 Updating the Predictive Pedestrian Model

Another objective was providing the data framework and tools for a pedestrian model that will accurately represent the average number and distribution of pedestrians in Venice at any time. The main input to this predictive model is the current traffic flow and congestion, and its predictive parameters are variables such as the increase in tourist population. The usefulness of this model stems from its ability to algorithmically fill in missing data, spatially and temporally.

This gap in the data occurs naturally, because it is simply unrealistic to account for the current and future location of every individual in the city. The model is essential, as it fills this gap by generating the missing data and predicts potential congestion.

A pedestrian model was created originally by Cody Smith at Redfish, a New Mexico based company. In 2015 the model was transferred to the VPC for work to continue in house. The pedestrian model predicts the movement of agents, or simulated Venetians and tourists, through the streets of Venice. The distinction between Venetians and tourists is important because both groups move in very different ways. The code on which the model is based is complex and has a lot of errors including pedestrians traveling outside of roadways due to an outdated street map and not representing updated quantities. The team worked to update a network of streets so the model in the future can run fluidly.

3.5.1 Updating a Digital Street Network of Venice

Geographical Information Systems (GIS) are used to model a given area using Global Positioning System (GPS) coordinates. Several GIS can be used to model a variety of features about any given area, whether it is landscape, buildings, or street networks. Each type of feature is modeled as a different layer. This way, if a user wanted to see the street network in detail, they could pull up only that layer, but if they wanted to also see what buildings were on each street, both layers could be opened, allowing the cumulative features to be shown. Figure 27 is an example of how digital mapping software uses layers to display diverse information.

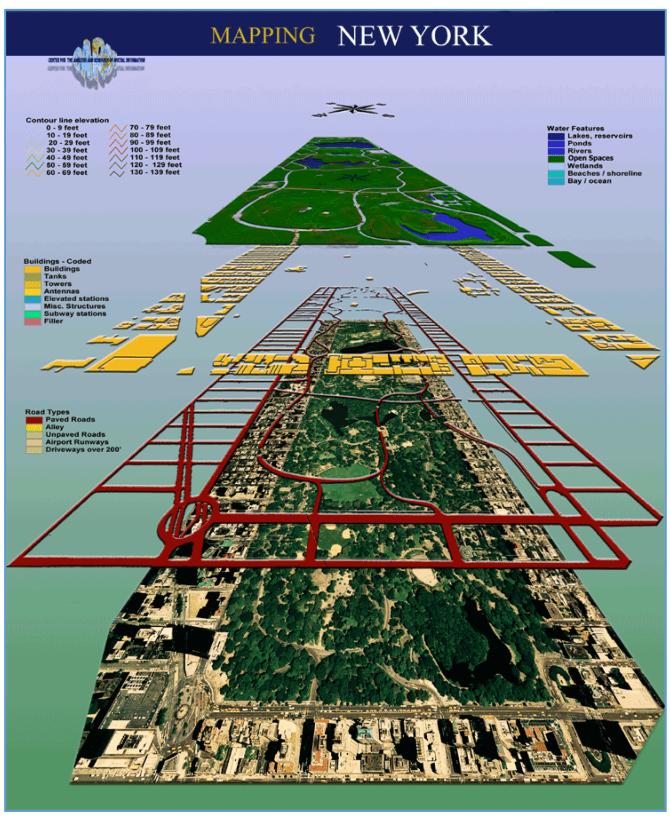

Figure 27: An example of GIS layers used to separate features of New York City

One of the major advantages of using GIS software is that since it uses GPS coordinates, it is also able to calculate the real length and area taken up by any given feature. In the street layer, the features are each street, and the software would be able to give the width, length, and area of any street provided.

The team continued the progress completed by previous WPI VPC collaborators on creating a digital model of the city of Venice. This includes work on a variety of GIS layers which have been created through the Quantum Geographical Information System (QGIS) computer application. Existing layers include, but are not limited to shops, bridges, churches, and streets. The street network of Venice is modeled in two different ways; one layer that maps street segments as simple lines, and one layer that incorporates the width of the streets as well. The layer with which the team worked is the street segments layer. This is the layer that will be used to guide pedestrian agents in the pedestrian model. The team worked with the existing layer, which can be overlaid on a Google street map in order to complete the segmentation of the streets.

Segmentation of streets is completed by ensuring that streets that contain multiple intersections are separated into the smaller pieces between the intersections. If one street had two intersections along its length, it would therefore be divided into 3 segments. Different segments are highlighted as a different color, with each street having multiple sections as defined by the number of other streets intersecting with it. Additionally, street squares, or *campos*, were modeled to be sure that pedestrians coming out of every street had all possible options to cross the square.

The purpose of ensuring proper segmentation is that when the layer is used in the pedestrian model, it is important that the pedestrian agents have the appropriate options to choose from when they approach an intersection. The proper segmentation creates nodes at the intersection point of any different sections. These nodes act as a decision point for the pedestrian. If it was a four-way intersection, but the main street was not properly segmented, then the agent may not see the intersecting street as an option.

The final part of segmenting the streets was to assign the proper municipal codes to the segments. Streets in the City of Venice have a corresponding code. These codes were entered for each street segment, in the layer. As well as the length as determined by the GPS coordinates.

3.6 Navigation Application

The team developed a concept for a mobile application, whose ambition is to facilitate navigation in the streets of Venice, using the software called Google Justinmind. The core functionality of this application was modeled after the yellow street signs in Venice – earlier explained in Section 2.2.2 Navigating the Streets– and intended to be used as a personalized yellow sign on demand. In order to achieve the feeling of carrying the city's navigation system on a mobile device, both *Nizioleti* and yellow signs in the application needed to resemble the real signs in Venice. The team utilized online software to identify the font used in both types of signs by analyzing images of each sign. After identifying a closest font matches, the team purchased those fonts from an online service called MyFonts and installed them for use in the Google Justinmind software.

The team also used use-cases and mockups to design what the app could look like and how it might work.

3.6.1 Planning the Application

The application prototyping was carried out in Google Justinmind, which is a drag-and-drop design platform. Once the application is opened, it displays a loading screen, which then transitions to the home screen after the functionalities have been loaded. All three sections in the main screen of the application are interactive fields created by tools in the Justinmind software. The reason for using Justinmind was to create a proof of concept which would be interactive and produce a user friendly prototype.

4 Results and Analysis

All manual and automatic pedestrian counts that were collected by the team will be used in creating a more accurate framework for the future development of a pedestrian model. As the VPC accumulates data, a predictive pedestrian model would be able to fill existing gaps more accurately.

4.1 Validating Previous Manual Counts

In 2013, a Worcester Polytechnic Institute (WPI) and Venice Project Center (VPC) team conducted counts at eight bridges with the goal of calculating the existing Level of Service (LOS) ratings for them. A detailed description of LOS is included in Section 2.2.5 Problems caused by Congestion. Additionally, they developed a spreadsheet that took these manual pedestrian counts and calculated what these counts would be in future years, starting in 2015. This calculation was based on the growing population. These predictions were completed on a bi-annual basis, so the first predicted year was 2015. The 2015 team visited three of the bridges that the 2013 team had included in their predictions: *Ponte de l'Anconeta, Ponte de l'Olio,* and *Ponte della Guglie*. Figure 28 shows the location of each of the bridges counted by the 2013 team, with callouts for the three bridges counted by the 2015 team. The team recounted at to test these predictions and the use of manual counts.

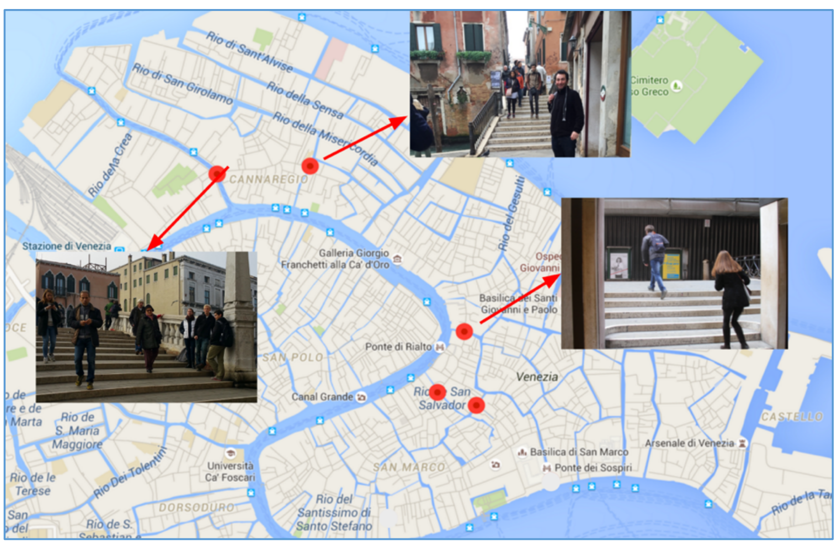

Figure 28: Three locations counted by the team distinguishing between Venetians and tourists

Each of the bridges revisited in 2015 was counted in a bidirectional method, distinguishing between Venetians and tourists as described in Section 3.1 . Counts were conducted at the peak times that were defined by the 2013 VPC team. These peak times span the hours of 11:00 - 13:00 and 15:30 - 17:30. The 2013 team recorded data in 20 minute segments. The first 15 minutes involved active counting, while the remaining five minutes were extrapolated from the first 15 minutes. This allowed for a variety of analysis including the direction of travel, and makeup of crowds during the morning as well as the afternoon.

Spreadsheets containing all of the data collected from 2015 manual counts can be found in Appendix B: Results of Manual Counting. Additionally, the comparison of LOS data from 2013 and 2015 can be seen in Table 2.

Table 2: The Level of Service ratings from 2013 and 2015

Level of Service Comparison					
Ponte della Guglie		Ponte de l'Anconeta		Ponte de l'Olio	
2013	2015	2013	2015	2013	2015
10.1	8	31.8	13	50	20

4.1.1 Pedestrian Flow

Since separate counts were taken for each direction of travel, it was possible for the 2015 team to compare the volume shifts in the morning and the afternoon. This made it possible to draw conclusions about certain bridges that may be used to commute for local Venetians, or used to travel to points of interest by tourists. All data for the bidirectional flow over the bridges is presented in Appendix B: Results of Manual Counting.

Ponte della Guglie:

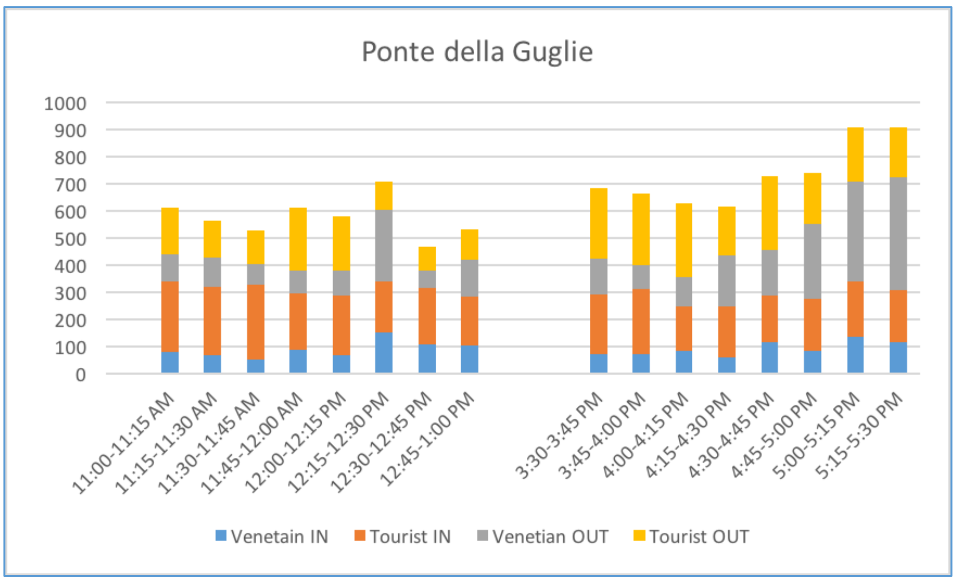

Figure 29: All data collected for Ponte della Guglie

The overall trend at this bridge showed 5,659 people moving East from the bridge towards the train station compared to 4,795 moving West, away from the train station. This trend was supported by the afternoon counts which had 3,569 pedestrians moving East and 2,297 pedestrians moving in. The morning peak time counts showed the opposite of both the afternoon and overall trends, with 2,498 moving West, away from the train station and 2,090 moving East.

The train station is the primary point of interest influencing the pedestrian flow over this bridge. In the morning visitors arrive and cross West into the city, while in the afternoon and evening they cross East out of the city. The stark difference in number of pedestrians leaving in the afternoon versus entering in the morning was likely unique to the day. Because train station traffic influences this differently bridge daily it is impossible to infer trends for each day based on one day of counts.

Calculating level of service for the bridge revealed that the bridge was never more congested than a LOS rating of A, or free-moving pedestrian traffic. The highest amount of flow counted by the team would need to be multiplied by 10 in order to reach an impassable rating of F.

Ponte de l'Olio:

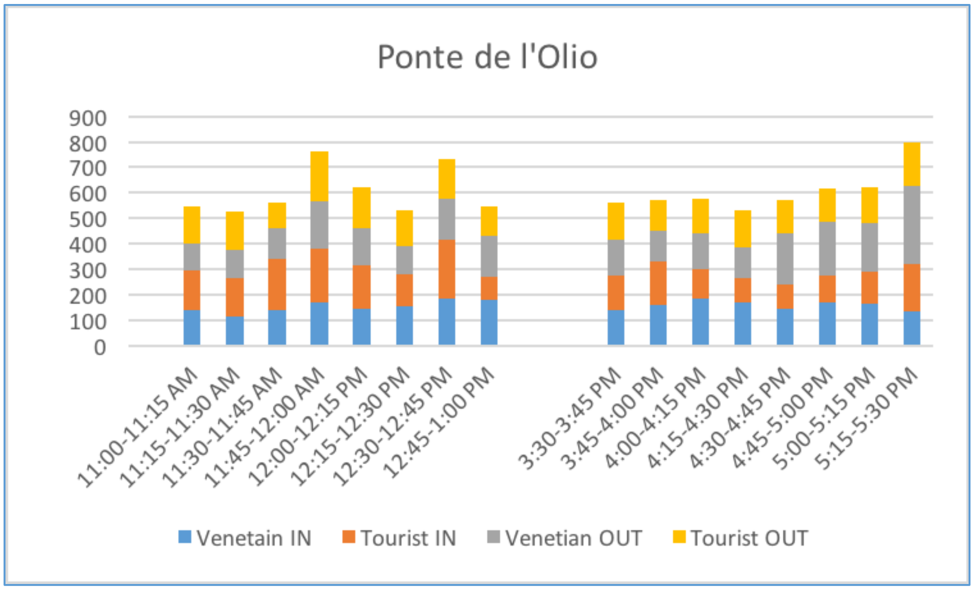

Figure 30: A graph of all of the data collected at Ponte de l'Olio

This bridge exhibited similar numbers for both movement South into the Rialto island and North out of the Rialto island. Over the course of the entire day, 24 more pedestrians traveled into the island than out of the island. 4,849 moved into the island and 4,825 moved out of the island. This equality was mirrored in both the morning and afternoon counts. There was a difference of 285 pedestrians in the morning and 261 in the afternoon. In the morning, 2,555 people were counted coming in, and in the afternoon 2,555 people were counted going out. This data is best seen in Figure 35.

This bridge is one of the main entrances to the island which is at one end of the Rialto Bridge. Since the Rialto is one of the most popular points at which to cross the Grand Canal, it could be understood that there would be a close to equal amount of pedestrians crossing the bridge in both directions.

The LOS rating for this bridge was the worst seen of any of the three bridges counted by the 2015 team. Twice in the morning and once in the afternoon, the bridge reached an LOS rating of B, still passable, but with the need to actively avoid slower pedestrians. The rest of the time, the bridge fell under the LOS rating of A. In order to reach an LOS rating of F, the largest number of pedestrians counted would need to be multiplied by four.

Ponte de l'Anconeta:

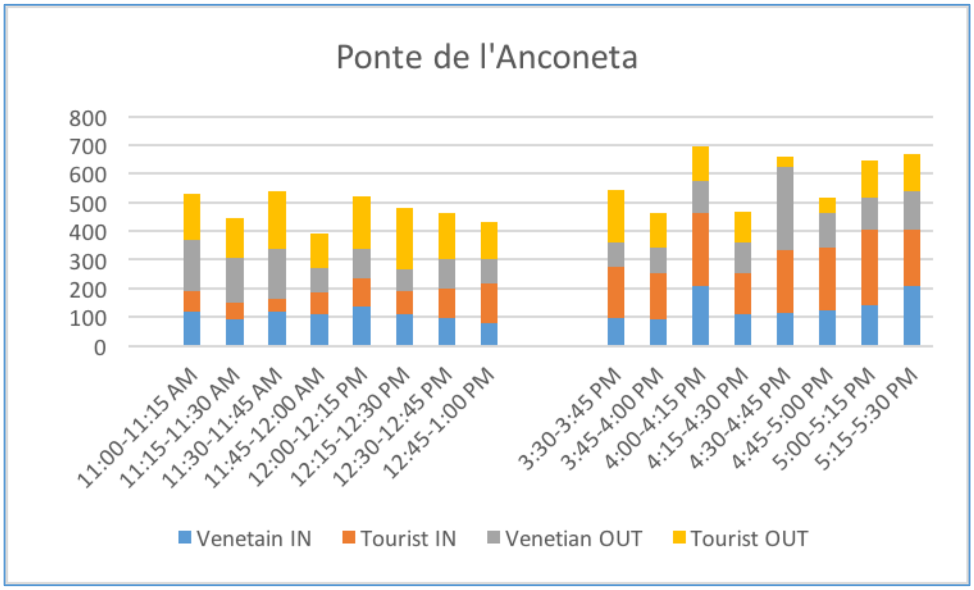

Figure 31: All data collected for Ponte de l'Anconeta

Similarly to *Ponte de l'Olio* this bridge experienced very equal flow across both directions across the entire day. The difference between the overall directions for the entirety of the day was 48 pedestrians with in being 4,259 and out being 4,211. The morning and afternoon also exhibited nearly perfectly opposite directional trends. In the morning, 1,529 people moved in and 2,283 went out. The afternoon saw 2,730 people moving in and 1,928 moving out.

This bridge is located farther down the main street of *Strada Nove* which is the same street at *Ponte della Guglie. S*ince it is farther away from the train station, the flow was more equalized, with more people going back and forth to shops and housing or hotels. It was still possible to see the same trend of the majority of people moving from the train station in the morning, and back towards it to leave the city in the afternoon.

This bridge had a level of B in one of the periods of 15 minutes. Otherwise the bridge exhibited a LOS rating of A. The largest flow that the team counted would need to be multiplied by five in order to reach the impassable level of F.

4.1.2 Population Demographics

Each of the counts was completed by distinguishing between Venetians and tourists. This distinction allowed for a study of the makeup of crowds and how they changed throughout the day.

Ponte della Guglie:

The graph of this data is shown in Figure 29. Over the course of the peak times, 6,327 tourists crossed the bridge, outnumbering the 4,127 Venetians who crossed. This trend of tourists outnumbering Venetians was consistent in both peak times independently as well. Counts were recorded every 15 minutes, and there was never a time when more Venetians had crossed than tourists.

Since this bridge is located on *Strada Nove*, which is a street connected to the train station and *Piazzale Roma*, the bus station, this trend was expected, as many tourists use the bridge to get to their hotels. Additionally, it has a great number of shops on it which attract many of the people visiting the city.

Ponte de l'Olio:

The graph of this data is shown in Figure 30. A total of 5,019 Venetians and 4,655 tourists crossed this bridge over the course of the two peak times. This shows an overall tendency of more Venetians than tourists, a pattern bolstered from the afternoon peak times. In the morning peak times 2,330 Venetians and 2,495 tourists crossed over the bridge. In the afternoon the trends switched to 2,689 Venetians and 2,160 tourists crossing. It was observed that the majority of residents who crossed the bridge were bringing children back from school, a conclusion reached from the observation of the presence of their young children with backpacks.

Since there are limited places to cross the Grand Canal, it makes sense that as school got out, many local families would be crossing *Ponte de l'Olio* since it is one of the main points of entry onto the island containing one end of the Rialto bridge. The comparison *Ponte de l'Olio* to other entrances to the island are explored in more depth in Section XXX from a case study completed on that island.

Ponte de l'Anconeta:

All data for this bridge is shown in Figure 31. From the totals of each of the peak times, 4,508 tourists and 3,962 Venetians crossed this bridge. Individually, the morning and afternoon peak times both agree with this trend, in the morning with 1,987 and 1,825 and the afternoon showing 2,521 and 2,137.

This trend is very similar to the one observed at *Ponte della Guglie*, which is to be expected as they are both located on the same main street, *Strada Nove.* The ratio at this bridge however is closer than that of *Guglie* since it is farther away from the larger shopping areas and the train station. Many of the people coming into the city may have already reached their destination or hotel.

4.1.3 Verification of Previously Established Predictive Formula

As described in Section 2.4 Manual Pedestrian Counting, the 2013 VPC team developed a spreadsheet and formula to predict future pedestrian populations across the seven bridges for which they completed peak time counts across. After comparing the data collected in 2015, it was seen that the raw counts collected in 2015 were lower than the counts taken in 2013 at *Ponte della Guglie, Ponte l'Anconeta* and *Ponte de l'Olio*. The peak flow counted at *l'Olio* by the 2013 team was 2,029 in 20 minutes compared to a maximum of 800 counted in 2015 over the course of 15 minutes. The same trends can be seen at both *Guglie* and *l'Anconeta*, 958 compared to 908 and 847 compared to 696 respectively.

For each bridge the 2013 team relied on data from only one or two days of collected data, each with 5 minutes of extrapolation for every 20 minutes of data produced. After this comparison of data, the 2015 team choose to not continue counts at the remaining 4 bridges after coming to the conclusion that the predictive spreadsheet was developed on too sparse of a field of data. one or two days is not significant enough time to properly obtain averages off of which future years of data can be predicted.

4.2 Rialto Full Day Count Data

An important piece of analyzing the movement within the city of Venice is analyzing the movement of pedestrians within each of the 126 islands. As the team looked to analyze the movement within individual islands, they compared options that would exhibit the highest flow of both Venetians and tourists. The team narrowed it down to two locations: St Mark's Square and the island on the South side of the Rialto Bridge. The island connected to the Rialto Bridge was chosen because it had 10 points of entry instead of the 28 that surrounded St Mark's The count was competed on Saturday, November 21st, 2015, which coincided with the celebration with the holiday of Salute, which celebrates the end of the plague of '63.[54] Each of the remaining 9 points as shown in Figure 32 of entry were counted from 7:00 – 19:00, the full results of which are shown in a spreadsheet included in Appendix C: Rialto Island Case Study Data and Appendix D: Rialto Island Case Study Individual Bridge Flow.

Figure 32: The total flow through each entry point

4.2.1 Pedestrian Flow Through the Island

Over the period of the entire day 138,910 pedestrians crossed in and out of the island. Data on the number of people moving through this specific island has never been collected. That said,

[54] Veneziasi

the count was executed on a Saturday, and also coincided with the holiday of Salute. While it is not representative of the flow during peak tourist times.

Overall, the net flow of pedestrians through the island resulted in 6,768 more pedestrians leaving the island than who entered the island. The first trend observed by the team was the contrast of the flow at all of the bridges versus at the boat stops. While each of the bridges connected to the island had very close to equal proportions of pedestrians crossing in and out, the boat stops exhibited a much higher net outward trends. Due to poor record keeping by counters at Boat Stop D, the data from this entry point is unable to be used in any other analysis besides total flow. The proportional pedestrian flow for each bridge can be seen in Figure 32.

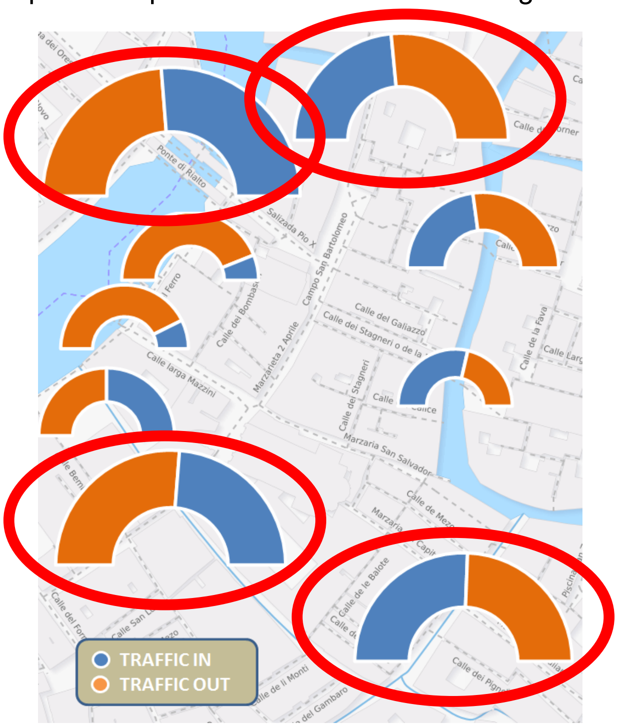

Figure 33: The four most used bridges around the island

After understanding the proportion of pedestrians crossing into and out of the island, each entry point was analyzed for the volume of pedestrians crossing it. Figure 34 shows that the Rialto Bridge and *Ponte de l'Olio* had the two largest numbers of pedestrians moving across them over the course of the day. There were four particular bridges that controlled the majority of pedestrian flow into and out of the island as can be seen in Figure 33. The remaining five bridges each had less than half the traffic flow of the least traveled of the top four bridges. This suggests that pedestrians do not use all bridges equally, a critical behavior any future model would need to consider.

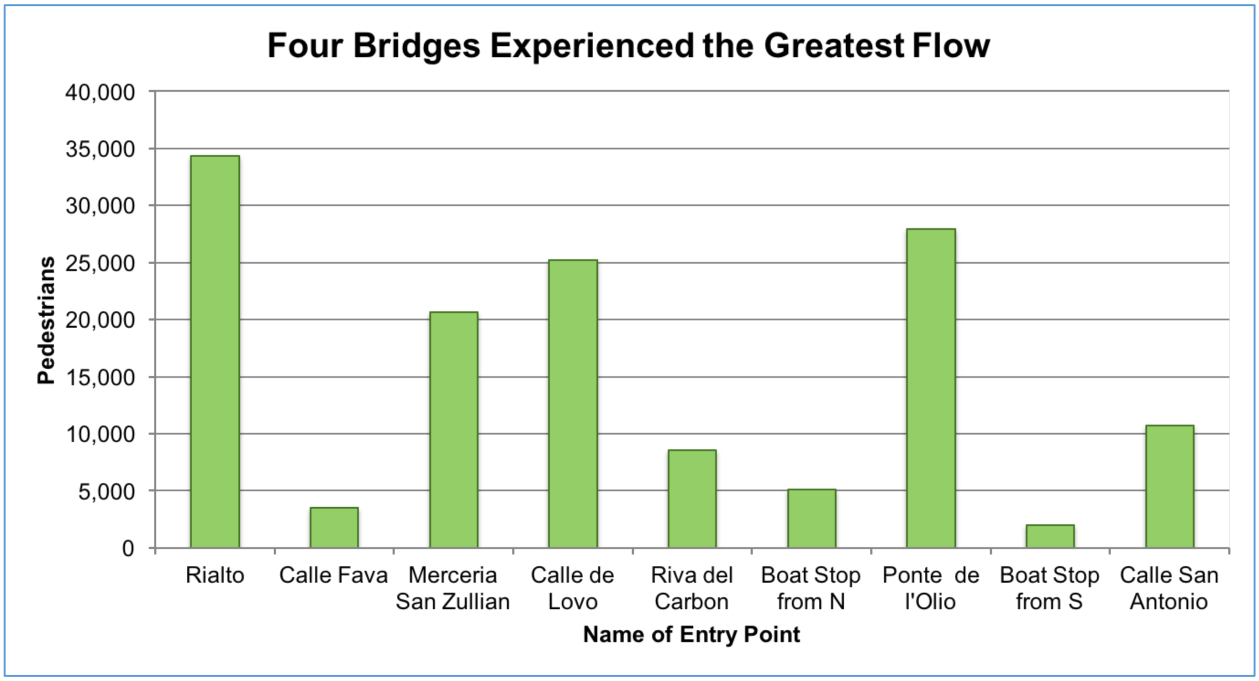

Figure 34: A graph of the flow through all of the entry points around the island

Counts across the Calle San Antonio bridge were taken by a camera which the team installed. This camera was validated beforehand by manual counts to be accurate within 13%, however, on the day of the count, it was incredibly rainy and many people were carrying umbrellas. As discussed in more detail in Section 2.2.3 Obstacles to Pedestrian Movement, umbrellas can cause an unknown degree of error in counts taken by the camera, supplying a falsely low number. On the day of the count, while this risk was understood, the team did not have the resources to place manual counters on the bridge and choose to accept the possibly increased margin of error.

4.2.2 Peak Times for Bridge Congestion

After understanding the flow over the course for the entire 12 hour count, the team divided the data into morning, afternoon and early evening sections. Morning being defined as the first four hours from 7:00 to 11:00, afternoon as the next five hours from 11:00 to 16:00 and early evening as the final three hours from 16:00 to 19:00. Each of these time periods were observed to have unique pedestrian flow.

In the morning, the flow through the island picks up slowly, particularly the movement of pedestrians into the island. A total of 12,645 people enter, while 16,598 leave the island. However, all of these pedestrians are not evenly distributed through each of the points of entry. Pedestrians primarily enter from the North side of the island likely from neighborhoods in the *Canarregio* section of the city or *Strada Nove* and the train station at *Ferrovia*. The South side and Boat Stop C has a majority of pedestrians crossing out of the island.

In the afternoon, a total of 32,487 pedestrians enter the island and 33,832 leave. During this period of time, all of the entry points experience near equality in the comparison of pedestrians crossing in and out of the island. Boat Stop C, which experiences consistently higher departures than arrivals throughout the day, has the highest its number of entrances during the afternoon. This consistency doesn't only apply to the direction of the flow, it is also reflected in the total flow across each of the entry points. The total hourly flow for each of the entry points is much more consistent than at any other time during the day.

Finally, in the early evening, 15,835 pedestrians entered the island and 18,206 left. While this maintains the overarching trend of a greater amount of pedestrians leaving instead of entering, the flow at each entry point was the opposite of the morning. People were moving North, entering through the Southern entry points and crossing out of the island on the Northern points. This therefore could mean that pedestrians are moving back towards *Canarregio* of the train station in order to go home or to leave.

In order to understand more of the trends over the course of the entire day, the team analyzed each of the bridges individual pedestrian flows. The example included here is of the Rialto bridge, the rest can be found in Appendix D: Rialto Island Case Study Individual Bridge Flow. In Figure 35, the pedestrian flow into the island was plotted in blue next to the flow out of the island in orange on a clustered column graph. Throughout the course of the day, there were six hours that experienced significantly more pedestrians crossing to leave the island. During only three hours during the day were there a noticeable majority of pedestrians moving into the island. From the hours of 8:00 to 11:00 more pedestrians were traveling into the island than traveling out of the island. This flips from 12:00 to 14:00 where the majority can be seen moving out, possibly returning home for lunch, or crossing back North after attending Salute. At 15:00 a majority of pedestrians crossing into the island was observed for the last time. It can be speculated that this would be pedestrians returning to the Southern side of the bridge after lunch; however, it is also possible it was a trend driven by the more arbitrary movements of pedestrians. From 16:00 – 19:00 when the count concluded, the majority of pedestrians were crossing to the North side of the bridge. From additional counts conducted on the *Ponte de l'Olio* the team was aware of a tendency of Venetians to cross in this direction when returning from picking up their children from school which could be a large factor in this movement.

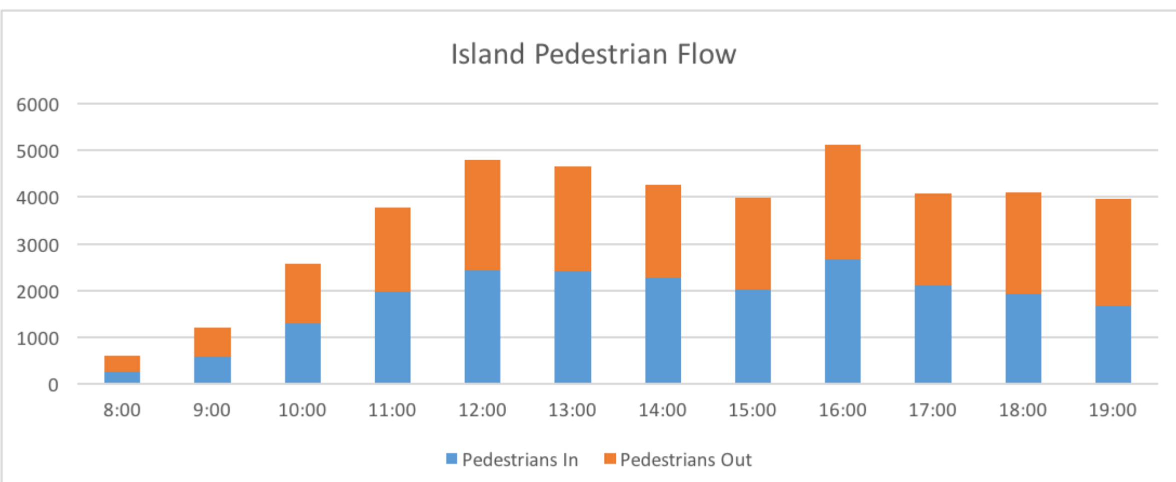

Figure 35: Pedestrian flow distinguished by direction from the Rialto Bridge

4.3 Automatic Counts

Automatic counts were introduced and tested in this project due to the shortcomings of manual counts. The most desired benefit of automatic counts is continuous collection of year round data, which minimizes the gaps in the collected pedestrian information and would improve predictions. Figure 36 shows the locations and views of the 12 cameras used in Venice.

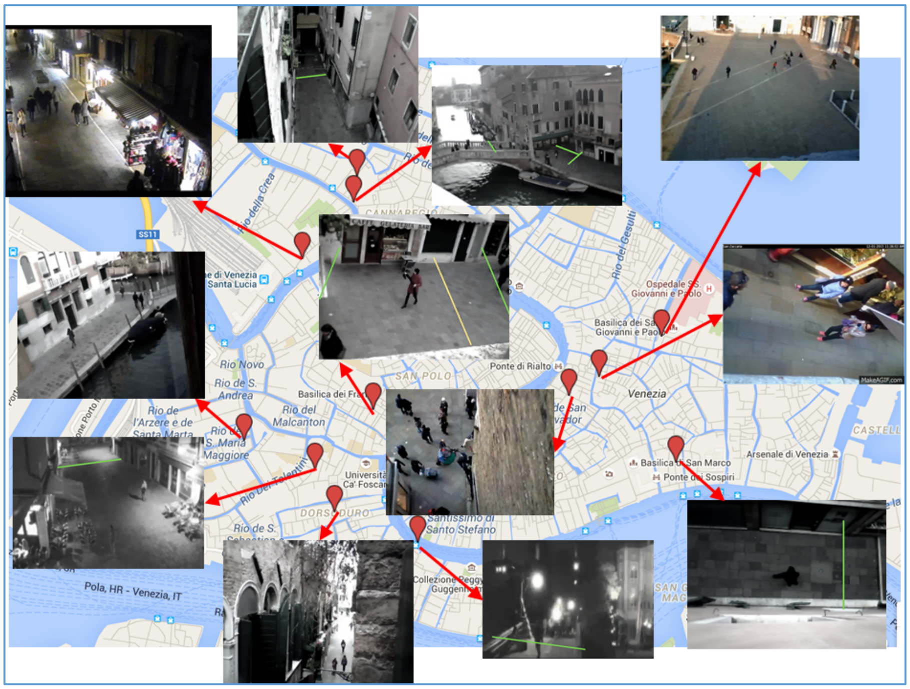

Figure 36: A graphic depicting the view from the 12 cameras used by the team

4.3.1 Usable Data

To determine if the cameras were a viable solution for filling gaps resulting from manual data collection, the team had to ensure their accuracy and reliability. Verification counts, as described in Section 3.3 Autonomous Counting were taken at least twice at each camera site, in order to test their consistency. The results from the verification counts showed that only three cameras were accurate and consistent within fifteen percent. Appendix E: Automatic Count Verifications shows a list of the cameras and their verification counts. *Calle Ghetto Vecio, Ponte de Castello* and *San Giovanni e Paulo* were the only three valid cameras. However, *Ponte de Castello* and *San Giovanni e Paulo* faced other challenges as described below, so were not tallied in the results reported below.

4.3.2 Potential Data to be Collected from Automatic Counts

One bridge determined to be accurate within fifteen percent and viable was the *Calle Ghetto Vecio* camera. It can be used to illustrate the type of data and trends that can be distilled from automatic counting software. The location of this camera was right on the edge of Venice's Jewish Ghetto. The Ghetto is the center of Jewish life in the city and there are many Venetians who live in this area with few hotels for tourists.

Peak times were observed at 9:00, 12:00 and 17:00. These times correlate to people leaving for work or school, people coming home for lunch and then people returning home at the end of the work day. This pattern can be seen in Figure 37, an average of one week worth of data

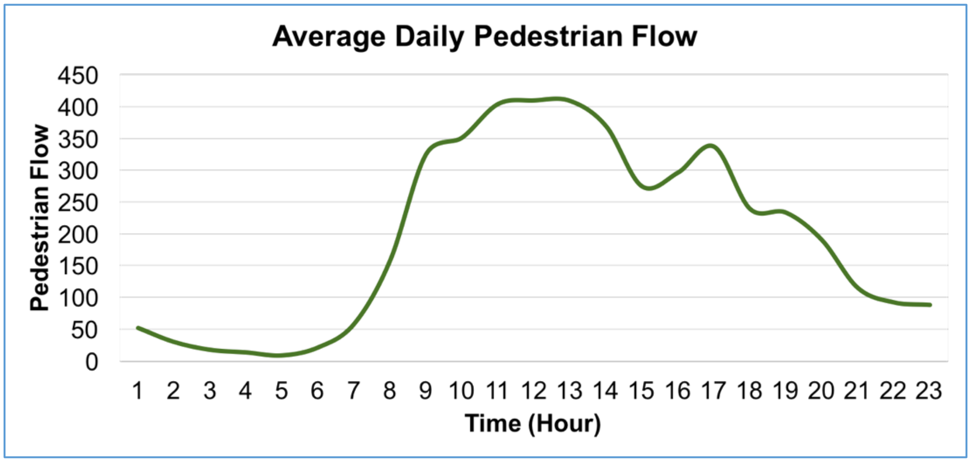

Figure 37: A week of collected data averaged to show daily trends of pedestrian movement

Besides peak times there is a near identical movement of people in versus people out of the street seen in Figure 38. This implies the street is not a destination but a through way that people use throughout the day to get from one place to another.

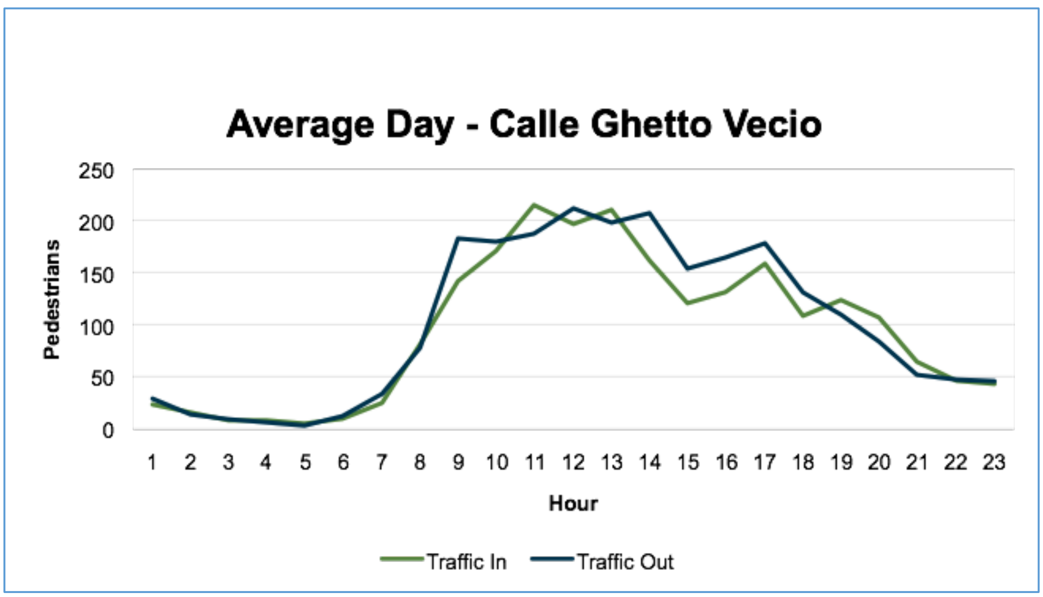

Figure 38: The same average day, with an added distinction of direction

In the final days of this project, a city camera located at *Strada Nouve* had lines placed at different distances away as seen in Figure 39. The team was able to see the scaling of the data from the most accurate data coming from the closest line, and the least accurate coming from the farthest line. The team speculates this is because the closest line has the steepest angle.

Figure 39: View from the Strada Nuove city camera

4.3.4 Problems with Automatic Counting Systems

The cameras and software depend on reliable WiFi. Unfortunately, in the private residences of Venice WiFi isn't necessarily reliable. Many participants complained of cameras slowing their WiFi and poor connections after the camera had been installed. An internet speed test was completed at *Ponte de Castello* showing a download speed of 5.1 Mbps without the camera to 4.8 Mbps with the camera. Also with slow and spotty WiFi, packets of video streams cannot be sent to the company in New York fluidly therefore, spots of data are missed.

Umbrellas, strollers and large groups of people may also cause the software to miscount. When the camera is installed at a birds eye view, looking straight down, umbrellas hide people in the small congested streets of Venice as seen in Figure 40. Multiple people can stand underneath an umbrella and be missed by the algorithm. The same goes for babies in strollers. A manual counter would know that a stroller hides a child that should be counted as a pedestrian. However, because the stroller obstructs the view of the child's head from the camera the child is not counted. And when the camera is not placed at a bird's eye view but rather at a slight angle, large groups of people, or people walking close together can distort the cameras view. The camera and software only 'see' one head when there could be many right behind one another.

Figure 40: Umbrellas obscuring pedestrians moving down the Rialto bridge

Also the software does not know how to distinguish between people. While this may be an advantage because no one person is being identified there is a lack of knowing if the same person is lost and crossing over the line multiple times in a short period of time. The same occurs with Venetians versus tourists. The capability does not exist yet to differentiate between a local and a visitor, a crucial piece of information for the pedestrian model as the two different types of people behave in different ways.

While the counting ability can depend on weather and other conditions, logistical problems were also experienced. The cameras unfortunately are not waterproof. This is a simple solution to fix; however in a city like Venice with a lot of rain and flooding it is important to use a tool that can withstand the environment. The functionality of the city cameras that were used in this project were unaffected by rain or water And not effected by WiFi.

Not all aspects of the camera were bad. Some positives that were discovered, for example the software is able to count people both day and night in setting with limited lighting. Without taking into account the umbrellas, the cameras were still able to function in all types of weather therefore allowing for counts year round. Since the cameras are able to be used year round in all types of weather they would count during the peak tourist season as well. The software had no problems counting upwards of 2,000 plus people in an hour.

4.4 Destination Site Counts

Using *Annuario del Turismo*, or the annual Tourism Report, the team reorganized existing data regarding museum and point of interest (POI) attendance throughout the city. This data can be used in order to properly directing tourist agents in the pedestrian model.

The top two city museums can be found in Saint Marks as seen in Figure 41. The Doges Palace skews the information in the graph, so a second graph, found in Figure 42 displays the comparative popularity of the rest of the museums without the Doges' Palace.

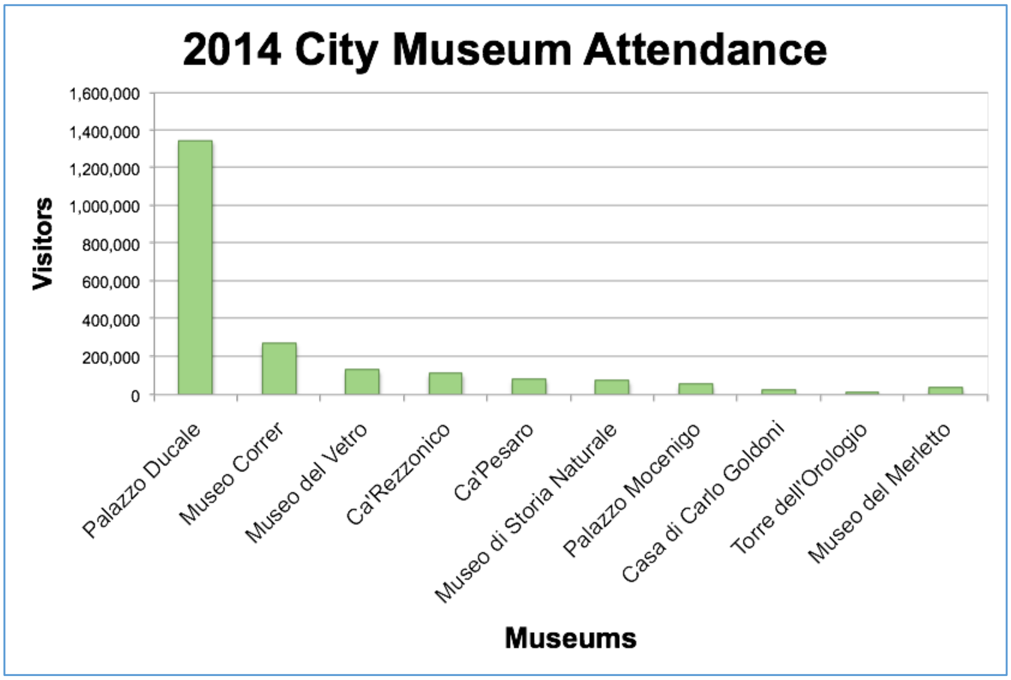

Figure 41: Numbers collected from the tourism report regarding Museum attendance

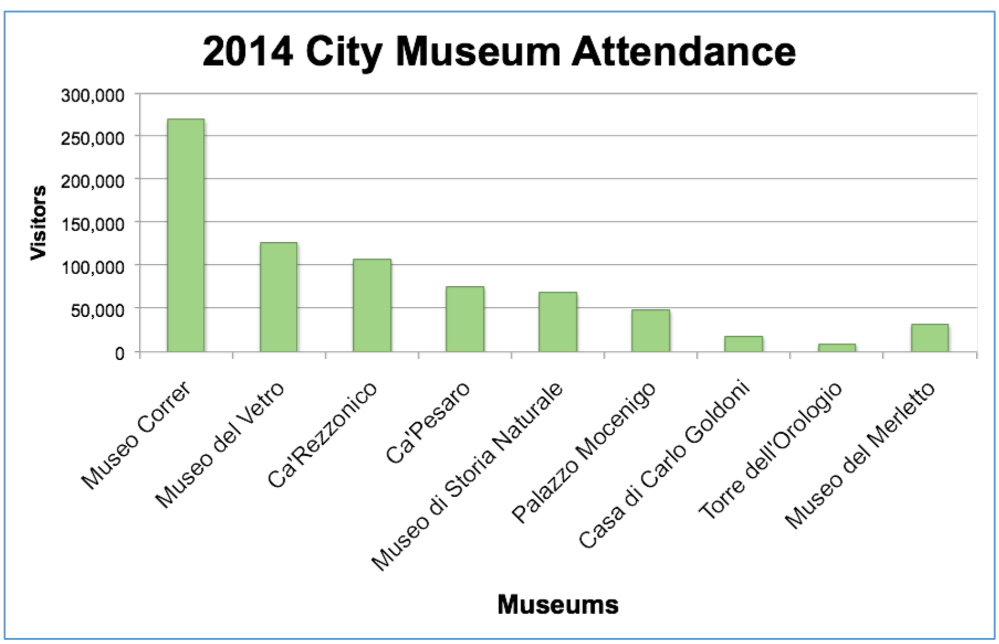

Figure 42: Attendance numbers for all the museums except the Palazzo Ducale

Tourists do not attend these museums year round but rather in a centralized time during the year. Specifically the time between April and October have the largest number of tourists visiting these museums. With the largest peaks in May and then August seen in Figure 43.This could be attributed to school trips in May and summer vacation in August. This adds the temporal aspect of accuracy to the model, having the appropriate number of tourist agents to each attraction each month.

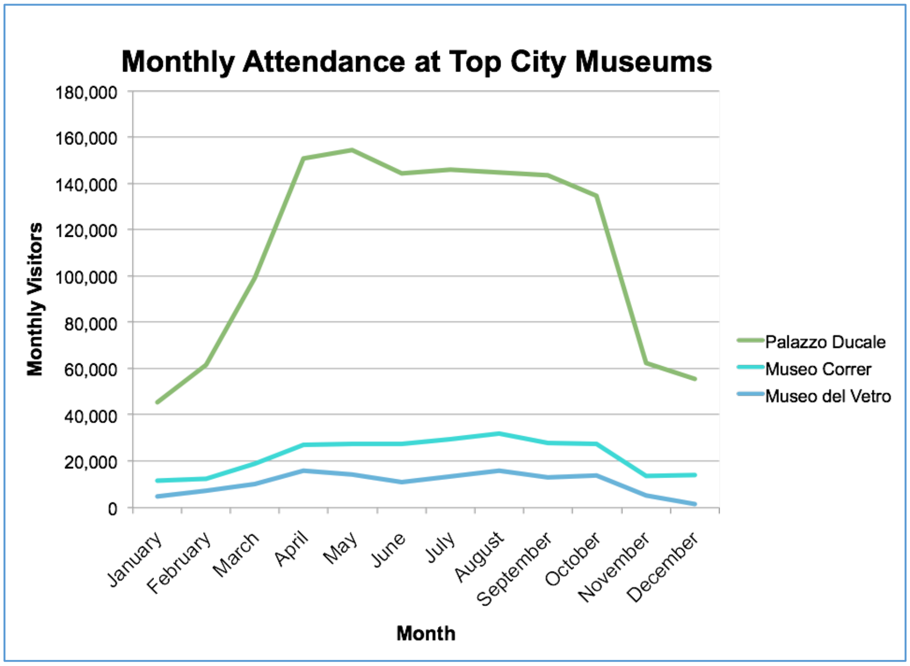

Figure 43: Attendance at the top 3 museums graphed by month over the course of 2014

4.5 Completed QGIS Layer of Streets of Venice

As described in Section 3.5.1 Updating a Digital Street Network of Venice, the QGIS layer that contains the line segments representing all of the streets in the city was updated in order to provide a more up to date and comprehensive base from which to build a pedestrian model. The existing layer was updated in multiple distinct ways.

The layer was overlaid over Google maps and remaining streets were added to the layer with the proper street names and GPS lengths. While most of the streets were properly modeled already, making sure that all streets were correctly connected is vital to accurately modeling the movement of pedestrians throughout the city. The team encountered an issue when the plugin for the Google Streets layer failed but the layer was able to be finished using Google Hybrid view and Apple maps.

Additionally, each of the *campos*, or squares, throughout the city was connected to be sure that all entrances to the *campo* were directly connected to each other. This accurately modeled the movement of pedestrians through the square and avoided inaccurate modeling of congestion around the perimeter where the previous paths were drawn. An example of before and after of *Campo Santa Margherita* (Margheritaville) is included in Figure 44.

Figure 44: Before and after pictures depicting how intersections, or campos were connected

The completion of this layer signified an improvement of previous attempts to create predictive pedestrian models where agents could be seen walking on top of buildings and through canals as highlighted in Figure 45.

Figure 45: A screenshot of the existing model with pedestrians moving through canals and buildings

4.6 Nizioleto Mobile Application Concept

At the completion of the project a concept for an app was designed so that it can be made in the future.

The application provides guidance through a real-time responsive compass, which would point in the general direction of the preselected destination instead of using turn by turn instructions. The home screen of the application is shown in Figure 46. The user will be able to select one of the nine destinations from a list, which contains all existing yellow signs used by the city. The only exceptions are the red emergency sign and the directional sign for the hospital, which is similar to the yellow signs in functionality, but the hospital option is colored blue instead.[1] These destinations include popular attractions and services. During an emergency, the user can choose the red destination sign as shown in Figure 47, which gives directions to the nearest and less crowded island exit. The purpose of the application was to simulate a navigation experience as similar as possible to following the real signs of Venice. In order to achieve this experience, the fonts *Archive Modern II* and *Revista Stencil* were used for the characters inside the yellow and *Nizioleti* signs, respectively.

Figure 46: Home screen of the Application

Figure 47: Emergency mode within the Application

Another method of destination input is the street address on the *Nizioleto* sign, which the user can type in by tapping the search icon as seen in Figure 48. After selecting a destination, the user can then follow the direction of the compass. The application also contains GPS functionality in a traditional Google Maps platform, but given the maze-like network of the streets of Venice this may not prove helpful in identifying the user's current location. This functionality can be turned off and by tapping the GPS icon to save battery or turned on to identify current location. In order to handle the shortcomings of GPS, the application also includes a user input option that identifies current street location by taking a street sign photo or moving a allowing the user to move a pin on the map where he or she thinks the current location is as seen in Figure 49.

Another functionality that facilitates navigation is activated by tapping the map icon on the bottom left of the screen. After tapping the icon, a trail of the user's path is drawn on the map, leaving digital breadcrumbs to the places he or she has travelled.

Figure 48: Manual input of users location

Figure 49: Input by taking a picture of a nearby street sign

Some of the challenges presented during prototyping include embedding the Google map of Venice and keeping track of pixel coordinates of each icon and element. A simple Uniform Resource Locator (URL) of the city's map did not format the element content for proper use in the design. The solution involved getting the source code of the embedded city map and pasting it onto a different design element in the form of HyperText Markup Language (HTML). Each screen of the application on Google Justinmind is separate, so when making changes to one screen, they had to be translated to the rest. Changes that involved moving around or resizing elements, proved challenging, because they needed to have matching pixel coordinates, widths and lengths. The finalized application design includes a total of six screens: the loading screen, home screen, search screen, street photo screen, location screen, and trail screen as illustrated in Figure 50. The team will pass on the application design to the VPC for future planning and coding.

Figure 50: The app providing directions and then tracking the users movement as they walk to their destination

5 Recommendations and Conclusions

5.1 Feasibility of Manual Counts

Manual counting has been the methodology used by teams collecting data since 2009, and with the advance of technology, the team felt it was time to investigate new alternatives.

With the comparison of the data collected at the same bridges in 2013 and in 2015, the team determined that the fundamental flaw of manual counting was that it did not collect a large enough sample size of data to be predictive. This made it impossible to make any kind of predictions for the future, or reliable averages on which to base assumptions of pedestrian trends. While the team acknowledges the value of the manual counting in the Rialto Island case study, it can be observed that the camera was more consistent than the manual counts. Gaps in data from Boat Stop D would not be present if it had been monitored automatically.

From these conclusions, the team recommends that future use of manual counting is limited to validating the accuracy of automatic counting methods.

5.2 Feasibility of Automatic Counts

While continuous data collection was not previously feasible for the VPC using antiquated manual counting methodologies, automatic counting opens up the possibility of collecting year round data. In the past it has been impossible to tell if pedestrian data was being influenced by unusual circumstances because other data did not exist for comparison. Having data on every month throughout the year would allow the VPC to make better recommendations for summertime traffic management based on summertime data rather than based on extrapolations from data taken in the fall.

The system used by the team was successful in collecting large amounts of data on pedestrian movement throughout the city. The cameras measured large numbers of pedestrians in short periods of time, showing that the system has the ability to count in high traffic areas. Additionally, Placemeter is able to determine the direction of traffic flow across a measurement point. This could allow future predictive models to understand the direction of pedestrian flows throughout the city in order to disperse agents accurately.

The team concluded that the combination of cameras and Placemeter software used were not consistently accurate within the group's established 15% margin of error. Only 15 out of 42 hours of manual verifications of Placemeter's pedestrian count numbers were within a 15% margin of error of the manual counts performed by the team. The 27 counts made by Placemeter which were outside the margin of error are the result of a wide range of factors, including babies obscured by strollers, umbrellas, carts and deliveries. The most substantial, however, is poor WiFi connections and non-uniform lighting. Many of these variables remain unexplored, so the most prevalent source or sources of discrepancy for each set of counts cannot be statistically identified.

This team was able to isolate two variables which likely contributed the most to the increased margin of error. Adequate WiFi signals and unobstructed views of the street they are monitoring.

All three cameras which obtained counts consistently accurate within 15% were located in places with strong WiFi or had wired connections such as the city cameras. Cameras in locations with weak WiFi sent incomplete data packets, making pedestrians skip past the line instead of crossing through it, causing the software to undercount. The minimum WiFi strength required to eliminate the stifling of data packets was unable to be determined. Wired cameras supplied by the city were able to eliminate this variable. Cameras also need a direct overhead view of the street, unobstructed by obstacles such as shutters. These obstacles can create blindspots, and can allow pedestrians to move through the street while remaining uncounted. Additionally, a camera view with a lower angle can cause pedestrians to be hidden by the people in front of them.

More testing is required before automatic counting using video cameras and Placemeter software can be deemed feasible for future use. The current market price of Placemeter's software is $150 per measurement point per month or $1,800 per year. In order to justify the purchase of the service, statistically isolating the most important variables that affect the counts is crucial. If the partnership with Placemeter is not renewed in future years, it does not seem likely that the VPC could continue testing or using cameras to automatically count pedestrians without writing its own algorithm.

The team has specific recommendations for future teams to more effectively isolate the variables contributing to error in the current camera counting system. One factor that is crucial to understanding the cameras is the appropriate camera angle. To test camera angle the team suggests taking three cameras and placing them at three separate heights on a building. Have all three cameras be pointing at the same line on the ground, this way the top camera will have the most overhead view and the bottom camera the most straight on view. From the results of this test, preformed at various times and locations, the ideal camera angle will be confirmed.

More work also needs to be done in order to isolate the WiFi problems as well. In depth tests need to be done to determine the affect of a camera constantly streaming video over WiFi. Speed tests should be done at different points of the day on different WiFi systems with and without the camera plugged in. The 2015 team did this to a small extent but did not have time to accrue a significant sample size.

In the future the team also recommends placing cameras on the city lights. Moving forward the city of Venice will be implementing their own research to smart lights, a design by Oreste Venier. These smart lights will be hard wired for power and some for WiFi. A camera placed with the light would give the best angle, appropriate lighting, and good enough WiFi or wired internet for the cameras to run smoothly. This was not something the team was able to test as the city has not yet started this initiative, however contacts in Venice implied this technology would enter the testing phase in 2016.

Other recommendations include seeing what Placemeter's new sensor has to offer. To do so the team recommends placing a camera and a sensor at the same spot to see which is more accurate. Also the sensors work of off cell phone signal and not WiFi so testing could show increased reliability.

5.3 Recommendations for the Development of the Application

The development of a mobile application modeled after the artistic concepts created by the team would be incredibly powerful if linked with live data. With potential data collected from automatic counting and the predictive model, directions could be dynamic and users could be shown how to avoid major congestion. Live data updates could prove to be vital in the case of an emergency, acting as a guide towards exits for anyone who has the application, whether they are Venetian or tourists.

A potential partnership with the Nizioleto 2.0 or the rolling yellow sign initiative could allow all of the ideas to run off of the same centralized database, keeping continuity between the different navigational aids.

It is recommended that the development of this application begins immediately.

5.4 Development of a Pedestrian Model

The development of an agent based predictive pedestrian model for the city of Venice would have the potential for understanding pedestrian flow in the city. Manual counts, automatic counts, points of interest data, and the new pedestrian graph lay the framework for a predictive pedestrian model.

5.4.1 Automatic Counts

Having an automatic counting system established throughout the city will provide critical data on pedestrian movement which can be used to populate the model. Data gathered using cameras, once proven to be consistently accurate, can be a constant stream of informtion into the model. Also, with more data points and longer spans of time counted assumptions can be made with higher accuracy than single day counts. The more locations and times the model has inputted the better predictive qualities it will have.

5.4.2 Points of Interest

Knowing peak times and places is crucial for the pedestrian model. The agents will be pulled towards attractors based on this information. The model knows where they are arriving from, where they are staying and now where they are going. Knowing the two main museums are in Saint Marks square will draw pedestrians to this square accordingly. And then less so to the other museums around the city.

Going forward it will be important to keep updating information on attractions throughout the city. The best way to do this currently will be to continue gathering data from the tourism report. Future teams should look into collecting and linking day to day museum attendance data to the model. This idea can be expanded to private tourist destinations within the city and public transportation.

5.4.3 Pedestrian Graph of the City

With an updated graph of the city streets the framework for the entire model is set. Without an accurate street map that the agents can follow, there is the possibility for false congestion points and inaccurate predictions. The finished graph will make all of the data gathered relevant in the future model.

Appendices

Appendix A: Proposal to Placemeter for Academic Use of their Software

Application for Academic Use of Placemeter

By,

The Worcester Polytechnic institute Venice Project Center, Streets Team

Introduction:

We believe in efficient transportation because everyone's time is valuable.

Mobility affects everyone in the world. People travel daily to work, to the grocery store and to visit tourist attractions. When there are too many people on the roads problems start to arise. In 2010 commuters in Beijing, China were stuck in a traffic jam which stretched over 60 miles for more than a week. This was one of the worst examples of a traffic dilemma the world has ever seen. While this example was an extreme case, traffic is a current and daily problem all over the world. People spend on average of 35 hours per week in traffic in Europe, which totals to 75 days or 20% of the year. Many factors contribute to these traffic problems including accidents, influx of people, poor visibility and confusion. To combat growing traffic concerns most cities deploy tactics like public transportation; buses, trains, subways, walking and bike paths, all to give people alternative ways to get where they are going. But in some cities around the world these solutions are not an option.

Venice, Italy is a city like no other. There are no cars, bikes or trains within the city. The main forms of transportation are walking or using the city's only form of public transportation, boats. When there is an influx of people, there are limited options the city can utilize to alleviate the congestion. While many factors contribute to the growing problem of street mobility, the biggest factor is the high volume of tourists. Venetians are more focused, going to work, the supermarket, and home. Tourists instead, are trying to see as many sights as possible. They walk slowly and stop to take pictures in the middle of roadways and do not understand the complicated maze that makes up the streets of Venice. The total length of the streets in Venice is four times the size of the Boston Marathon, in total, around 105 miles. However, picture 30,000 other people also running the Marathon in streets roughly half a meter (2 feet) wide, barely bigger than the arm length of the average human. The streets in Venice seem to be permanently crowded. Additionally, while modern cities often have the opportunity to expand sidewalks, add lanes to roads, and increase the geographical footprint of the city, Venice's framework is restricted by ever rising seas and the antiquity of its infrastructure.

Overcrowding in Venice is not a new problem. Over the last 25 years the Worcester Polytechnic Institute (WPI) Venice Project Center (VPC) has made significant contributions to handling Venice's perpetual mobility dilemma. The VPC has worked on alleviating congestion by modeling pedestrian behavior in the floating city. Once complete, these models could be used to help Venice optimize its pedestrian infrastructure by guiding tourists and Venetians down less-crowded side streets. Efforts to control tourism are made to try and protect the city, and are also a response to seasonal flooding (Aqua Alta) and large public events such as Carnival. This current method isn't sustainable, as the city has already accrued a great amount of debt, and much of the current action taken action taken is reactionary instead of preventative.

While substantial research has been done in the past, there are a lot of different ways to tackle this problem of overcrowding. The biggest issue to date is the need for more people and resources in order to simultaneously meet all the demands of the ever-changing population of

the city. Efforts have been made to create an autonomous pedestrian model that ideally would predict the movement of both tourists and Venetians; however, this data is constantly out of date and does not fully incorporate the entire city of Venice. The data collected by previous WPI Interactive Qualifying Project (IQP) teams is focused on Saint Mark’s Square, which is understandable due to its high volume of tourist traffic. The shortcomings of this approach rely on the fact that it is not very realistic when it comes to creating a fully autonomous model of the entire city. The method used for data collection has traditionally been manual counting, which is inevitably subject to human error. During peak tourism times, it can be overwhelming to keep track of so many people at once. As a result, the population may be over or under represented.

The team's project will be working towards enhancing the presentation of the existing data, collecting additional pedestrian counts, and filling the gaps of the data collected by past IQP teams. While some disconnected data and models exist, the goal will be working to collect year round data outside of just the main tourist attraction in Saint Mark’s Square, and expand across the entire city. This will allow any model created to encompass the peak tourism season as well as the downtime where more residential foot traffic is present. These goals are summarized in the group’s mission statement:

The comprehensive goal of this project is to contribute in alleviating congestion in the historic city of Venice by facilitating navigation of tourists through a mobile application and explore an automated approach of collecting data on pedestrian movement year-round.

This mission statement is further broken down into more concrete objectives, which the team looks to complete while in Venice. This effort aims to work towards better representing information that can allow the pedestrian flow in the city of Venice to be properly modeled.

Objective 1: Consolidate, Update, and integrate available information on Pedestrian Movement

Objective 2: Create a Digital Network of Streets

Objective 3: Update Existing Pedestrian Model

Objective 4: Prototype and application to facilitate navigation

How Placemeter can enable project success:

Upon arrival in Venice we plan on establishing a wide network of autonomous counting instruments to collect data across the city. Autonomous data collection would allow us to establish a perpetual data feed which could monitor the city of Venice year round. This would allow the VPC to create navigational suggestions based on real-time knowledge of crowd movement. Autonomous data collection is also far cheaper and more sustainable than other methods of data collection. Once a process is established, the cost of continuing collection is low. Furthermore, cameras could be placed at any point in the city where data collection is required unobtrusively and with little effort.

By using cameras instead of another counting technology we can take advantage of security camera networks such as Argos, a Venetian police camera network which already exists within the city. Tapping into existing camera networks which are spread throughout the city will allow us to collect a wide range of data using existing infrastructure. In addition to utilizing existing

infrastructure we will set up measurement points using any additional cameras you provide and in prerecorded videos.

The ability to use Placemeter data to prove our concept, and display to both the VPC and the City of Venice the effectiveness and the usefulness of having this year round data collection gives the team a chance to move the project a huge leap forward. The incredible accuracy of the software gives an unprecedented opportunity to expand the existing knowledge base studying the unique situation presented by this ancient city. Using Placemeter we would be able to collect data 24 hours a day, whereas past data collection has been limited by the availability of human counters. With the possibility of future speed tracking, each street could also be labeled with a Level of Service (LOS) rating, easily describing the level of congestion present in any street at any time.

Once the autonomous system is established and providing us with data we will link that data into a pedestrian model which mimics traffic in Venice. This rapid influx of data from all over the city will enormously expand the scope and accuracy of the model which is currently limited to the area around San Marks square. Increased data will make the model more accurate in its estimates of daily congestion and allow us to mimic pedestrian movement year round.

What you get out of it:

By sponsoring this study Placemeter would be helping to solve a well-established, and very pressing issue for the City of Venice. We are the eighth project team from WPI to work on the problem of street congestion in Venice since 2008. As the scope of this project includes not just mapping and tracking pedestrians throughout Venice, but also creating a live model to facilitate navigation, and possible model evacuation from the city, we expect work to continue on this project for many more years. With a proof of concept created by this year's project, there is a possibility that the WPI VPC could open up a permanent connection in order to continue the collection of this valuable data.

Furthermore the advantage of having a team on the streets of Venice is huge as we would be able to approach other organizations in our attempt to cover as much of Venice as possible. Once we arrive in Venice we plan on attempting to partner with the Venetian Police Department, the Basilico De San Marco, and other organizations who might have existing camera networks or be interested in establishing them. Our work with these organizations will raise awareness of Placemeter throughout Venice.

This partnership between our team and Placemeter has the potential to greatly increase the scope and effectiveness of our project as well as increase publicity and citable successes of your product. We hope to have the opportunity to continue working with you and helping take another step towards understanding the unique pedestrian situation in Venice.

Worcester Polytechnic Institute

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Appendix B: Results of Manual Counting

Ponte de l'Anconeta		Date:11/11/15	Width: 2.77 m					
Time	Venetian IN	Tourist IN	Total IN	Venetian Out	Tourist Out	Total Out	Total Flow	LOS
11:00-11:15 AM	118	74	192	175	165	340	532	13
11:15-11:30 AM	92	59	151	155	138	293	444	11
11:30-11:45 AM	117	45	162	175	201	376	538	13
11:45-12:00 AM	111	75	186	84	121	205	391	9
12:00-12:15 PM	138	96	234	104	182	286	520	13
12:15-12:30 PM	110	80	190	75	218	293	483	12
12:30-12:45 PM	95	102	197	104	163	267	464	11
12:45-1:00 PM	79	138	217	83	130	213	430	10
		TOTAL	1529		TOTAL	2273		
3:30-3:45 PM	97	177	274	86	183	269	543	13
3:45-4:00 PM	92	162	254	89	120	-60	194	5
4:00-4:15 PM	208	253	461	113	122	26	487	12
4:15-4:30 PM	109	146	255	104	107	-24	231	6
4:30-4:45 PM	114	219	333	289	40	118	451	11

4:45-5:00 PM	121	222	343	119	53	-157	186	4
5:00-5:15 PM	139	267	406	111	129	68	474	11
5:15-5:30 PM	210	194	404	136	127	23	427	10
		TOTAL	2730		TOTAL	263		
Ponte della Guglie		Date: 11/12/15	Width: 7.63 m					
Time	Venetain IN	Tourist IN	Total IN	Venetian OUT	Tourist OUT	Total OUT	Total Flow	Level of Service
11:00-11:15 AM	78	259	337	102	171	273	610	5
11:15-11:30 AM	66	253	319	107	135	242	561	5
11:30-11:45 AM	50	276	326	78	122	200	526	5
11:45-12:00 AM	88	205	293	86	231	317	610	5
12:00-12:15 PM	66	220	286	94	197	291	577	5
12:15-12:30 PM	152	188	340	264	102	366	706	6
12:30-12:45 PM	108	208	316	62	90	152	468	4
12:45-1:00 PM	105	176	281	136	113	249	530	5
		Total:	2498		Total:	2090		
3:30-3:45 PM	72	220	292	129	262	391	683	6

3:45-4:00 PM	70	242	312	88	263	351	663	6
4:00-4:15 PM	85	161	246	107	275	382	628	5
4:15-4:30 PM	61	185	246	189	178	367	613	5
4:30-4:45 PM	116	169	285	171	269	440	725	6
4:45-5:00 PM	82	191	273	278	188	466	739	6
5:00-5:15 PM	137	201	338	367	202	569	907	8
5:15-5:30 PM	116	189	305	417	186	603	908	8
		Total:	2297		Total:	3569		

Location: Ponte de L'Olio		Date: 11/23/15	Width: 2.7					
Time	Venetain IN	Tourist IN	Total IN	Venetian OUT	Tourist OUT	Total OUT	Total Flow	Level of Service
11:00-11:15 AM	141	151	292	110	145	255	547	14
11:15-11:30 AM	113	150	263	111	152	263	526	13
11:30-11:45 AM	139	200	339	124	96	220	559	14

11:45-12:00 AM	171	211	382	182	199	381	763	19
12:00-12:15 PM	144	171	315	144	163	307	622	15
12:15-12:30 PM	156	121	277	111	143	254	531	13
12:30-12:45 PM	185	231	416	161	154	315	731	18
12:45-1:00 PM	181	90	271	157	118	275	546	13
		TOTAL	2555		TOTAL	2270		
3:30-3:45 PM	136	138	274	139	147	286	560	14
3:45-4:00 PM	160	169	329	124	118	242	571	14
4:00-4:15 PM	185	117	302	139	134	273	575	14
4:15-4:30 PM	168	95	263	123	146	269	532	13
4:30-4:45 PM	142	99	241	198	131	329	570	14
4:45-5:00 PM	170	104	274	210	133	343	617	15
5:00-5:15 PM	164	127	291	191	142	333	624	15
5:15-5:30 PM	134	186	320	306	174	480	800	20
		TOTAL	2294		TOTAL	4825		

Appendix C: Rialto Island Case Study Data

Calle Fava			
Bridge Name:	Pedestrian IN	Pedestrain OUT	Hourly Net Flow
Record count at 7:15 AM	5	1	6
7:30	11	1	6
7:45	16	9	13
8:00 AM	27	17	19
8:15	42	27	25
8:30	53	43	27
8:45	65	56	25
9:00 AM	78	77	34
9:15	104	110	59
9:30	141	141	68
9:45	176	168	62
10:00 AM	212	202	70
10:15	255	241	82
10:30	292	290	86
10:45	346	344	108
11:00 AM	376	367	53
11:15	423	442	122
11:30	465	491	91
11:45	497	542	83
12:00 PM	533	602	96
12:15	557	664	86

12:30	599	742	120
12:45	637	801	97
1:00 PM	671	846	79
1:15	705	907	95
1:30	732	958	78
1:45	756	1007	73
2:00 PM	802	1103	142
2:15	824	1142	61
2:30	876	1189	99
2:45	897	1220	52
3:00 PM	942	1271	96
3:15	972	1330	89
3:30	998	1365	61
3:45	1030	1406	73
4:00 PM	1089	1471	124
4:15	1150	1519	109
4:30	1168	1611	110
4:45	1195	1670	86
5:00 PM	1223	1702	60
5:15	1303	1742	120
5:30	1333	1775	63
5:45	1352	1825	69
6:00 PM	1382	1845	50
6:15	1421	1915	109

6:30	1441	1958	63
6:45	1468	2007	76
7:00 PM	1514	2018	57

Ponte de Bareteri			
Bridge Name:	Pedestrian IN	Pedestrain OUT	Hourly Net Flow
Record count at 7:15 AM	10	26	36
7:30	21	56	41
7:45	60	129	112
8:00 AM	103	196	110
8:15	171	273	145
8:30	222	363	141
8:45	258	459	132
9:00 AM	318	562	163
9:15	379	682	181
9:30	499	879	317
9:45	633	1046	301
10:00 AM	808	1273	402
10:15	930	1477	326
10:30	1085	1740	418
10:45	1386	2048	609
11:00 AM	1542	2305	413
11:15	1808	2727	688
11:30	2007	3057	529

11:45	2232	3351	519
12:00 PM	2401	3643	461
12:15	2684	3953	593
12:30	2928	4237	528
12:45	3177	4503	515
1:00 PM	3460	4776	556
1:15	3743	5144	651
1:30	4011	5416	540
1:45	4239	5689	501
2:00 PM	4456	5932	460
2:15	4708	6229	549
2:30	5009	6554	626
2:45	5265	6885	587
3:00 PM	5572	7144	566
3:15	5859	7417	560
3:30	6164	7766	654
3:45	6459	8012	541
4:00 PM	6717	8302	548
4:15	7032	8549	562
4:30	7418	8766	603
4:45	7718	9004	538
5:00 PM	7992	9168	438
5:15	8329	9396	565
5:30	8631	9607	513

5:45	8951	9763	476
6:00 PM	9242	9969	497
6:15	9469	10140	398
6:30	9729	10314	434
6:45	9974	10467	398
7:00 PM	10110	10607	276

Calle de l'Ovo			
Bridge Name:	Pedestrian IN	Pedestrain OUT	Hourly Net Flow
Record count at 7:15 AM	17	46	63
7:30	39	106	82
7:45	69	190	114
8:00 AM	106	281	128
8:15	150	374	137
8:30	202	468	146
8:45	265	612	207
9:00 AM	337	771	231
9:15	447	958	297
9:30	576	1271	442
9:45	725	1480	358
10:00 AM	889	1753	437
10:15	1121	2042	521
10:30	1346	2405	588
10:45	1622	2726	597

11:00 AM	1916	3070	638
11:15	2118	3353	485
11:30	2399	3620	548
11:45	2711	3903	595
12:00 PM	3079	4228	693
12:15	3407	4531	631
12:30	3842	4792	696
12:45	4236	5041	643
1:00 PM	4685	5274	682
1:15	5051	5534	626
1:30	5358	5755	528
1:45	5658	5952	497
2:00 PM	6023	6226	639
2:15	6299	6427	477
2:30	6646	6663	583
2:45	6994	6965	650
3:00 PM	7253	7252	546
3:15	7511	7596	602
3:30	7865	7995	753
3:45	8251	8268	659
4:00 PM	8653	8651	785
4:15	8995	8952	643
4:30	9414	9253	720
4:45	9795	9615	743

5:00 PM	10203	9913	706
5:15	10641	10206	731
5:30	11069	10491	713
5:45	11421	10730	591
6:00 PM	11806	10961	616
6:15	12126	11164	523
6:30	12515	11427	652
6:45	12914	11783	755
7:00 PM	13267	12027	597

Riva del Carbon			
Bridge Name:	Pedestrian IN	Pedestrain OUT	Hourly Net Flow
Record count at 7:15 AM	21	31	52
7:30	31	44	23
7:45	46	107	78
8:00 AM	68	148	63
8:15	95	242	121
8:30	117	278	58
8:45	139	324	68
9:00 AM	167	371	75
9:15	208	472	142
9:30	233	526	79
9:45	298	644	183
10:00 AM	350	739	147

10:15	425	883	219
10:30	536	983	211
10:45	637	1106	224
11:00 AM	748	1207	212
11:15	844	1332	221
11:30	936	1445	205
11:45	1043	1562	224
12:00 PM	1138	1678	211
12:15	1283	1777	244
12:30	1440	1857	237
12:45	1573	1960	236
1:00 PM	1718	2066	251
1:15	1829	2166	211
1:30	2015	2281	301
1:45	2121	2381	206
2:00 PM	2207	2443	148
2:15	2296	2545	191
2:30	2409	2633	201
2:45	2506	2719	183
3:00 PM	2595	2843	213
3:15	2718	2925	205
3:30	2810	3009	176
3:45	2920	3119	220
4:00 PM	3055	3227	243

4:15	3176	3357	251
4:30	3322	3446	235
4:45	3429	3557	218
5:00 PM	3538	3615	167
5:15	3788	3664	299
5:30	3881	3770	199
5:45	3962	3868	179
6:00 PM	4079	4007	256
6:15	4135	4094	143
6:30	4190	4175	136
6:45	4278	4281	194
7:00 PM			

ACTV Boat Stop C			
Bridge Name:	Pedestrian IN	Pedestrain OUT	Hourly Net Flow
Record count at 7:15 AM	0	11	11
7:30	0	58	47
7:45	0	99	41
8:00 AM	0	142	43
8:15	0	200	58
8:30	0	240	40
8:45	0	291	51
9:00 AM	0	320	29
9:15	0	452	132

9:30	0	487	35
9:45	30	576	119
10:00 AM	37	632	63
10:15	48	648	27
10:30	56	718	78
10:45	104	869	199
11:00 AM	121	977	125
11:15	140	1091	133
11:30	165	1172	106
11:45	165	1253	81
12:00 PM	205	1341	128
12:15	249	1412	115
12:30	269	1511	119
12:45	288	1598	106
1:00 PM	309	1695	118
1:15	342	1742	80
1:30	367	1836	119
1:45	375	1900	72
2:00 PM	406	2027	158
2:15	420	2131	118
2:30	431	2251	131
2:45	462	2330	110
3:00 PM	498	2509	215
3:15	511	2600	104

3:30	552	2793	234
3:45	552	2915	122
4:00 PM	609	2991	133
4:15	622	3107	129
4:30	659	3229	159
4:45	688	3316	116
5:00 PM	710	3450	156
5:15	734	3606	180
5:30	753	3749	162
5:45	753	3852	103
6:00 PM	753	3920	68
6:15	753	4021	101
6:30	753	4146	125
6:45	753	4265	119
7:00 PM	753	4372	107

ACTV Boat Stop D			
Time	Pedestrians In	Pedestrians Out	Hourly Net Flow
7:15			0
7:30			0
7:45			0
8:00			0
8:15			0
8:30			0
8:45			0

9:00	21	1327	1348
9:15	0	0	0
9:30	43	326	369
9:45	12	171	183
10:00	19	252	271
10:15	8	56	64
10:30	23	91	114
10:45	31	83	114
11:00	364	1509	1873
11:15			0
11:30			0
11:45			0
12:00			0
12:15			0
12:30			0
12:45			0
13:00			0
13:15			0
13:30			0
13:45			0
14:00			0
14:15	7	95	102
14:30	19	41	60
14:45	18	84	102
15:00	16	99	115
15:15			0
15:30			0

15:45			0
16:00			0
16:15			0
16:30			0
16:45			0
17:00			0
17:15	195	864	1059
17:30	0	128	128
17:45	0	58	58
18:00	0	94	94
18:15	0	84	84
18:30	0	196	196
18:45	0	72	72
19:00	0	0	0

Rialto Bridge			
	Pedestrian IN	Pedestrain OUT	Hourly Net Flow
Record count at 7:15 AM	36	38	74
7:30	80	78	84
7:45	138	121	101
8:00 AM	216	186	143
8:15	300	267	165
8:30	374	369	176
8:45	477	471	205
9:00 AM	649	613	314
9:15	969	738	445

9:30	1214	946	453
9:45	1553	1192	585
10:00 AM	1876	1449	580
10:15	2307	1869	851
10:30	2743	2220	787
10:45	3240	2669	946
11:00 AM	3658	3052	801
11:15	4196	3483	969
11:30	4604	4013	938
11:45	5001	4663	1047
12:00 PM	5499	5320	1155
12:15	6021	5754	956
12:30	6472	6178	875
12:45	6934	6812	1096
1:00 PM	7323	7432	1009
1:15	7738	7935	918
1:30	8133	8408	868
1:45	8563	8806	828
2:00 PM	8938	9230	799
2:15	9435	9742	1009
2:30	9941	10157	921
2:45	10540	10597	1039
3:00 PM	10909	10919	691
3:15	11366	11378	916

3:30	11766	11954	976
3:45	12156	12484	920
4:00 PM	12654	13048	1062
4:15	13172	13422	892
4:30	13514	13848	768
4:45	13871	14280	789
5:00 PM	14242	14672	763
5:15	14545	15280	911
5:30	14828	15733	736
5:45	15080	16158	677
6:00 PM	15323	16589	674
6:15	15619	16972	679
6:30	15900	17302	611
6:45	16107	17677	582
7:00 PM	16330	18055	601

Ponte de l'Olio			
Bridge Name:	Pedestrian IN	Pedestrain Out	Hourly Net Flow
Record count at 7:15 AM	27	12	39
7:30	65	34	60
7:45	141	76	118
8:00 AM	194	114	91
8:15	281	157	130

8:30	387	206	155
8:45	533	271	211
9:00 AM	674	340	210
9:15	894	439	319
9:30	1172	573	412
9:45	1532	739	526
10:00 AM	1836	889	454
10:15	2255	1083	613
10:30	2722	1338	722
10:45	3241	1551	732
11:00 AM	3763	1802	773
11:15	4200	2102	737
11:30	4644	2473	815
11:45	5098	2753	734
12:00 PM	5671	3086	906
12:15	6014	3428	685
12:30	6454	3621	633
12:45	6864	4115	904
1:00 PM	7209	4456	686
1:15	7620	4826	781
1:30	7911	5160	625
1:45	8188	5429	546
2:00 PM	8499	5717	599
2:15	8806	6045	635

2:30	9139	6320	608
2:45	9472	6698	711
3:00 PM	9861	7075	766
3:15	10221	7445	730
3:30	10589	7791	714
3:45	11017	8147	784
4:00 PM	11683	8542	1061
4:15	11768	8867	410
4:30	12177	9319	861
4:45	12547	9824	875
5:00 PM	12899	10122	650
5:15	13119	10513	611
5:30	13389	10894	651
5:45	13635	11248	600
6:00 PM	13914	11684	715
6:15	14156	12067	625
6:30	14384	12462	623
6:45	14606	12591	351
7:00 PM	14827	13132	762

Calle San Antonio (Camera)		
	Pedestrian IN	Pedestrian OUT
8:00:00	2	3
9:00:00	91	61

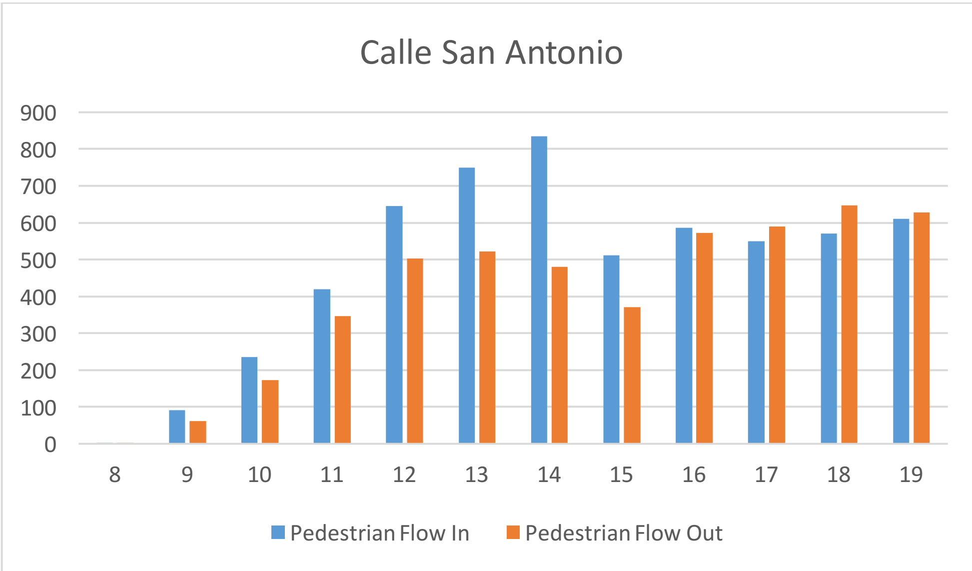
10:00:00	235	173
11:00:00	419	346
12:00:00	645	502
13:00:00	749	521
14:00:00	835	481
15:00:00	511	371
16:00:00	587	573
17:00:00	550	589
18:00:00	571	647
19:00:00	610	627

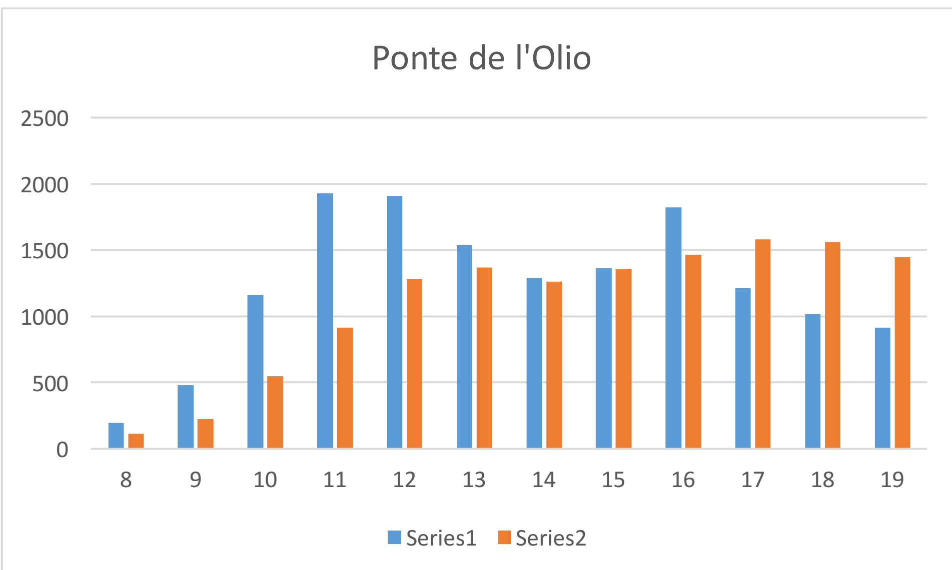
Island Total every 15 minutes				
Time	Pedestrian In	Pedestrian Out	Per Hour (In and Out)	
7:15	116	165		
7:30	131	212		
7:45	223	354		
8:00	244	353	714	1084
8:15	325	456		
8:30	316	427		
8:45	382	517		
9:00	507	1897	1530	3297
9:15	778	797		
9:30	877	1298		
9:45	1124	1193		
10:00	1080	1344	3859	4632
10:15	1341	1362		

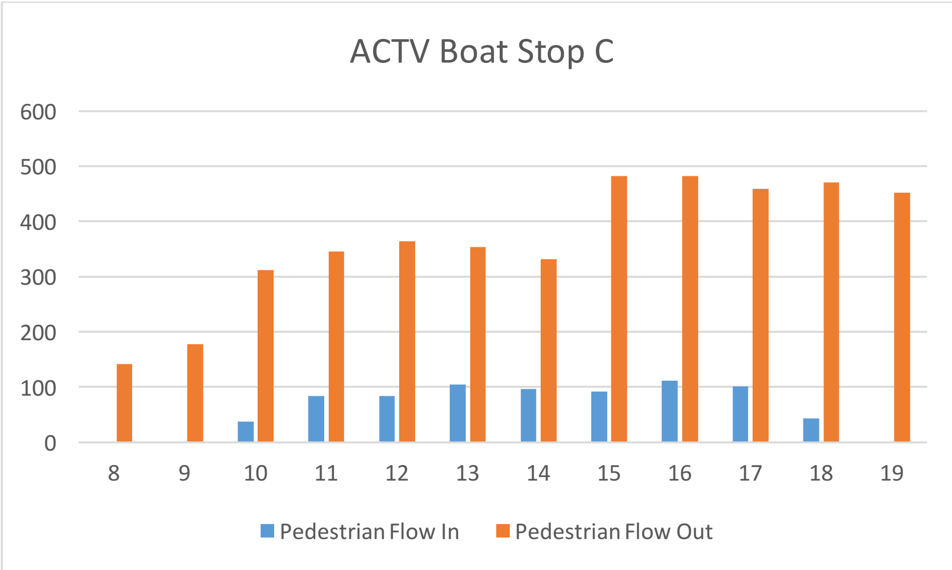
10:30	1462	1542		
10:45	1827	1702		
11:00	1914	2979	6544	7585
11:15	1605	1750		
11:30	1491	1741		
11:45	1527	1756		
12:00	1779	1871	6402	7118
12:15	1689	1621		
12:30	1789	1419		
12:45	1705	1892		
13:00	1666	1715	6849	6647
13:15	1653	1709		
13:30	1499	1560		
13:45	1373	1350		
14:00	1431	1514	5956	6133
14:15	1464	1678		
14:30	1682	1547		
14:45	1703	1731		
15:00	1601	1759	6450	6715
15:15	1528	1678		
15:30	1586	1982		
15:45	1641	1678		
16:00	2075	1881	6830	7219
16:15	1455	1541		
16:30	1757	1699		
16:45	1571	1794		
17:00	1564	1376	6347	6410

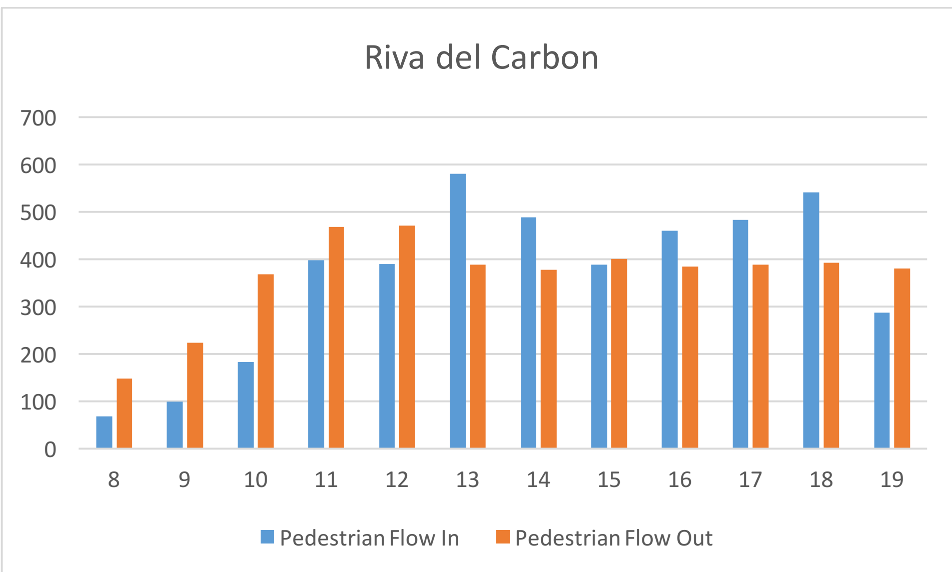
17:15	1847	2629		
17:30	1425	1740		
17:45	1270	1483		
18:00	1345	1625	5887	7477
18:15	1180	1482		
18:30	1233	1436		
18:45	1188	1401		
19:00			3601	4319
Total	60969	68636		

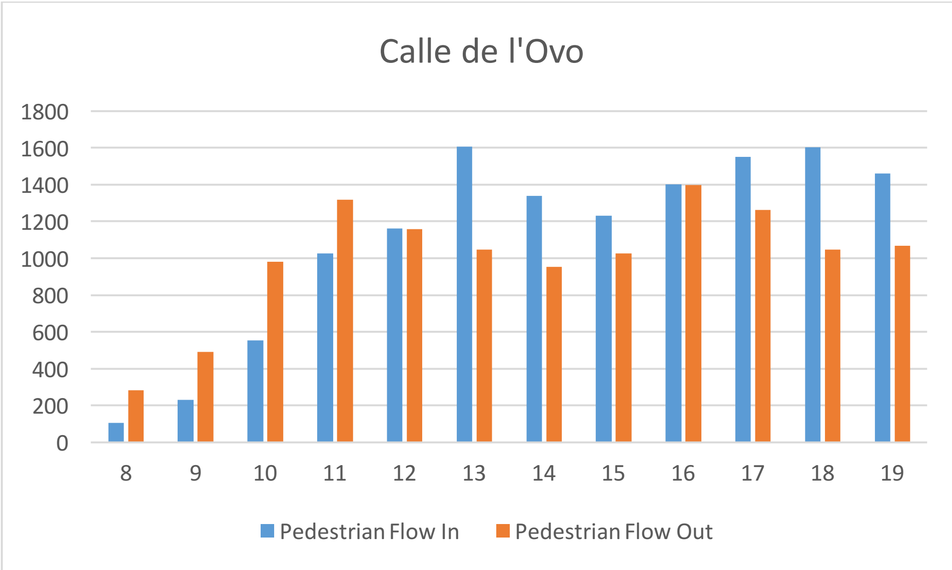
Appendix D: Rialto Island Case Study Individual Bridge Flow

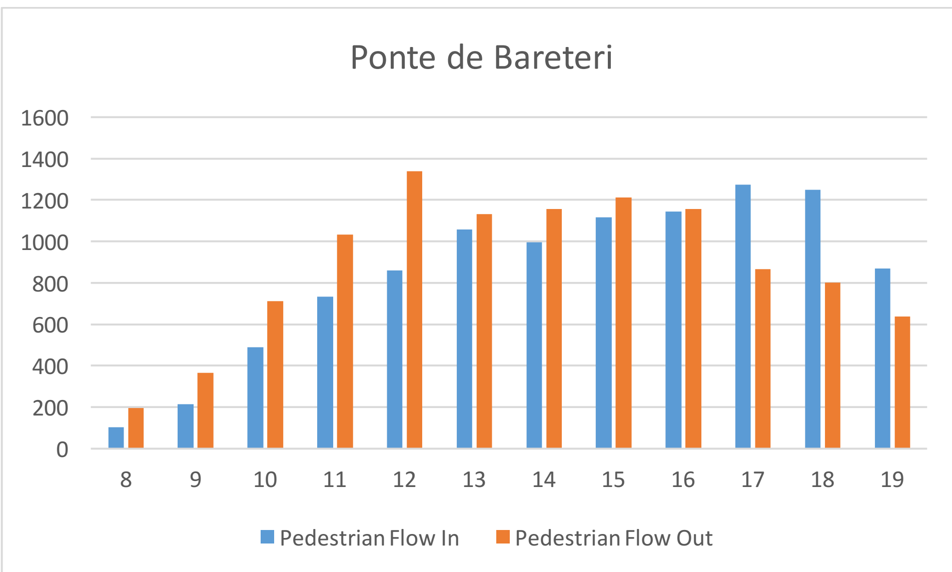


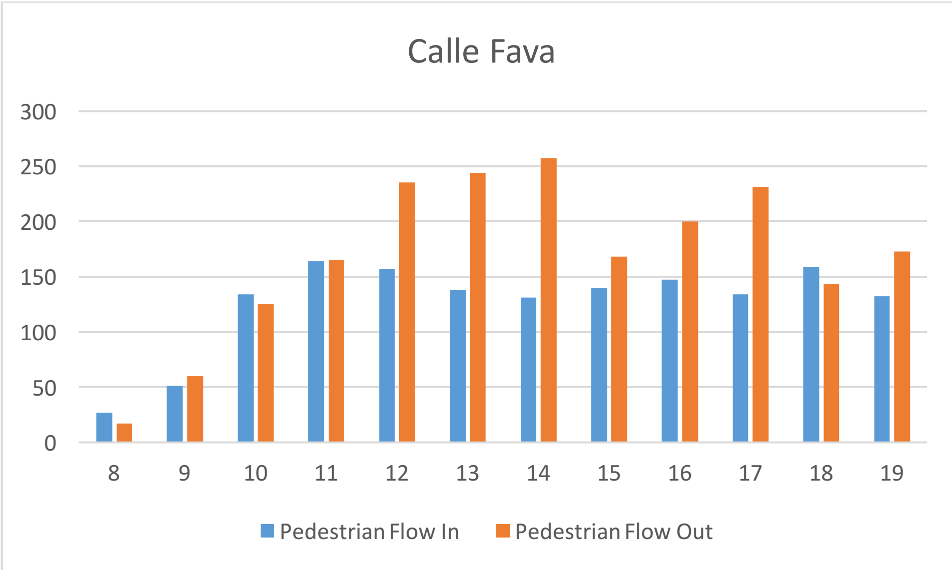


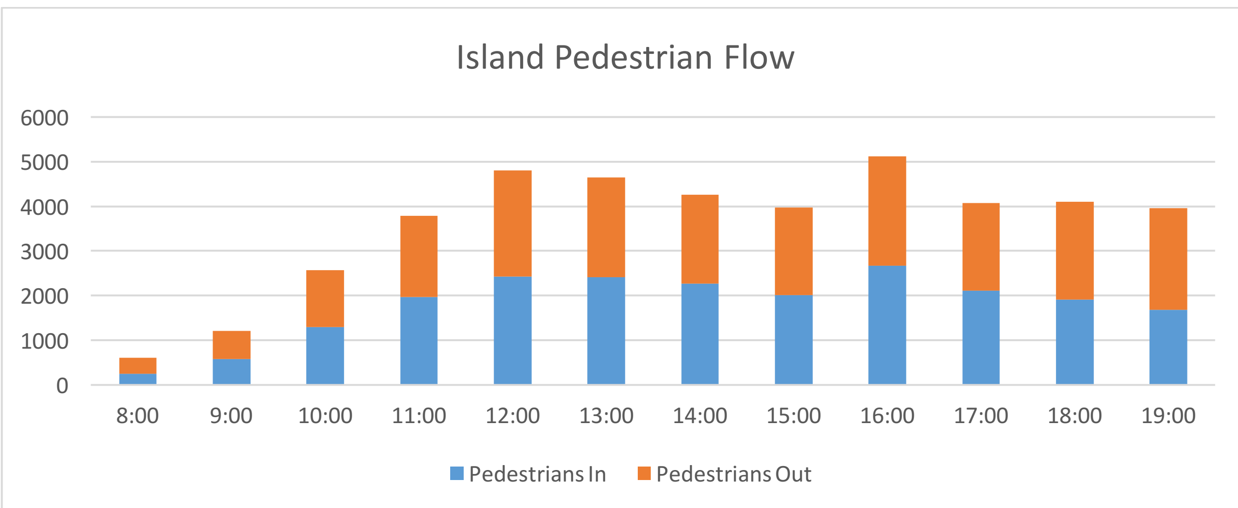

ACTV Boat Stop C
600
500
400
300
200
100
0
8 9 10 11 12 13 14 15 16 17 18 19
Pedestrian Flow In
Pedestrian Flow Out


Riva del Carbon
700
600
500
400
300
200
100
0
8 9 10 11 12 13 14 15 16 17 18 19
Pedestrian Flow In
Pedestrian Flow Out


Calle de l'Ovo
1800
1600
1400
1200
1000
800
600
400
200
0
8
9
10
11
12
13
14
15
16
17
18
19
Pedestrian Flow In
Pedestrian Flow Out


Ponte de Bareteri
1600
1400
1200
1000
800
600
400
200
0
8
9
10
11
12
13
14
15
16
17
18
19
Pedestrian Flow In
Pedestrian Flow Out


Calle Fava
300
250
200
150
100
50
0
8
9
10
11
12
13
14
15
16
17
18
19
Pedestrian Flow In
Pedestrian Flow Out


Island Pedestrian Flow
6000
5000
4000
3000
2000
1000
0
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
Pedestrians In
Pedestrians Out

Appendix E: Automatic Count Verifications

The Validation counts completed by the team. Bolded rows signify counts at locations which were determined consistently accurate within a margin of error of 15%.

Measurement Point	Date	Start Time	End Time	Manual Counts IN	Manual Counts OUT	Manual Total	Placementer Count IN	Placemeter Count OUT	Placemeter Total	Totals Percent Error (%)
S.Zaccaria	10/29/2015	11:00	12:00 AM	260	526	786	91	156	247	68.6
S.Zaccaria	11/10/2015	1:00 PM	2:00 PM	435	362	797	417	404	821	-3.0
S. Zaccaria	11/23/2015	1:00 PM	2:00 PM	336	323	659	288	264	552	16.2
S. Zaccaria	12/1/2015	10:00 AM	11:00 AM	262	188	450	219	179	398	11.6
S. Zaccaria	12/2/2015	10:00 AM	11:00 AM	263	162	425	204	132	336	20.9
San Zaccaria - Stream count	12/4/2015	10:00 AM	11:00 AM	278	151	429	361	220	581	-35.4
San Zaccaria - Stream count	12/4/2015	11:00 AM	12:00 PM	356	238	594	374	296	670	-12.8
Calle Ghetto Vecio	11/11/2015	5:00 PM	6:00 PM	230	254	484	163	203	366	24.4

Calle Ghetto Vecio	11/12/2015	11:00 AM	12:00 PM	256	338	594	225	314	539	9.3
Calle Ghetto Vecio	11/23/2015	3:00 PM	4:00 PM	225	126	351	200	187	387	-10.3
Calle Ghetto Vecio	12/2/2015	12:00 PM	1:00 PM	269	215	484	218	200	418	13.6
BSS - Alley	11/13/2015	3:00 PM	4:00 PM	1774	1442	3216	468	378	846	73.7
BSS - Walkbys 2	11/20/2015	10:00 AM	11:00 AM	1831	1083	2914	553	316	869	70.2
BSS - Alley	11/20/2015	10:00 AM	11:00 AM	1174	757	1931	288	156	444	77.0
BSS - Diagonal Walkbys	11/20/2015	10:00 AM	11:00 AM	1554	1139	2693	912	847	1759	34.7
BSS - Diagonal Walkbys	12/3/2015	9:00 AM	10:00 AM	1044	802	1846	848	706	1554	15.8
Angelo de Bocca/Frezeria	11/17/2015	10:00 AM	11:00 AM	826	523	1349	350	208	558	58.6
Angola Bocca di PIazza/Frezeria - W3	12/2/2015	12:00 PM	1:00 PM	67	63	130	63	50	113	13.1

Angola Bocca di PIazza/Frezeria - W2	12/2/2015	12:00 PM	1:00 PM	117	202	319	215	259	474	-48.6
Angola Bocca Di Piazza/Frezeria - W2	12/3/2015	9:00 AM	10:00 AM	966	403	1369	383	150	533	61.1
Angola Bocca di PIazza/Frezeria - W3	12/3/2015	9:00 AM	10:00 AM	76	33	109	80	50	130	-19.3
Ponte De Castello	11/17/2015	10:00 AM	11:00 AM	925	788	1713	834	648	1482	13.5
San Giovanni e Paulo	11/18/2015	2:00 PM	3:00 PM	470	434	904	339	336	675	25.3
Fondamente Procuratie - Walkby 1	11/19/2015	10:00 AM	11:00 AM	1082	448	1530	1268	281	1549	-1.2
Fondamente Procuratie - Walkby 2	11/19/2015	10:00 AM	11:00 AM	-Not Collected	-Not Collected	91	81	47	128	-40.7
Fondamente Procuratie - Walkby 1	12/1/2015	10:00 AM	11:00 AM	1229	472	1701	291	49	340	80.0

Fondamente Procuratie - Walkby 2	12/1/2015	10:00 AM	11:00 AM	40	24	64	47	46	93	-45.3
Fondemente Procuratie - Walkby 1	12/2/2015	10:00 AM	11:00 AM	61	24	85	52	23	75	11.8
Fondementa Procuratie - Walkby 2	12/2/2015	10:00 PM	11:00 AM	1264	502	1766	614	147	761	56.9
Ponte della Guglie	11/19/2015	10:00 AM	11:00 AM	1603	856	2459	428	359	787	68.0
Ponte della Guglie	12/2/2015	12:00 PM	1:00 PM	1141	1012	2153			1746	18.9
SGP - Bridge Entrance	12/2/2015	2:00 PM	3:00 PM	342	283	625	322	289	611	2.2
SGP - Statue Entrance	12/2/2015	2:00 PM	3:00 PM	321	456	777	252	238	490	36.9
SGP - Corner Entrance	12/2/2015	2:00 PM	3:00 PM	576	669	1245	55	85	140	88.8
SGP - Bridge Entrance	12/3/2015	9:00 AM	10:00 AM	388	296	684	420	347	767	-12.1
Strada Nouve - 2	12/4/2015	10:00 AM	11:00 AM	1256	930	2186	1212	782	1994	8.8
Campo Santa	12/4/2015	12:00 PM	1:00 PM	864	579	1443	581	526	1107	23.3

Margherita - Stream Count										
Campo Santa Margherita	12/5/2015	12:00 PM	1:00 PM	751	664	1415			1006	28.9
Campo Santa Margherita	12/5/2015	1:00 PM	2:00 PM	887	554	1441			1102	23.5
Accademia	12/4/2015	10:00 AM	11:00 AM	486	429	915	448	328	776	15.2
Accademia	12/5/2015	12:00 PM	1:00 PM	762	702	1464	1096	970	2066	-41.1
Accademia	12/5/2015	1:00 PM	2:00 PM	910	708	1618	892	742	1634	-1.0
Accademia	12/7/2015	11:00 AM	12:00 PM	1111	1070	2181	719	720	1439	34.0
Accademia	12/7/2015	12:00 PM	1:00 PM	1346	1235	2581	1016	1228	2244	13.1

Average daily flow for Calle Ghetto Vecio based on an average of all data collected from the camera at this location.

Time period start	Time period end	Calle Ghetto Vecio		
		Traffic In	Traffic Out	Total
11/27/15 0:00	11/27/15 1:00	23	29	52
11/27/15 1:00	11/27/15 2:00	16	14	30
11/27/15 2:00	11/27/15 3:00	8	9	17
11/27/15 3:00	11/27/15 4:00	8	5	13
11/27/15 4:00	11/27/15 5:00	5	3	8
11/27/15 5:00	11/27/15 6:00	9	12	21
11/27/15 6:00	11/27/15 7:00	24	34	58
11/27/15 7:00	11/27/15 8:00	80	77	158
11/27/15 8:00	11/27/15 9:00	142	183	325
11/27/15 9:00	11/27/15 10:00	171	180	351
11/27/15 10:00	11/27/15 11:00	216	188	404
11/27/15 11:00	11/27/15 12:00	197	213	410
11/27/15 12:00	11/27/15 13:00	210	199	409
11/27/15 13:00	11/27/15 14:00	162	208	369
11/27/15 14:00	11/27/15 15:00	121	154	275
11/27/15 15:00	11/27/15 16:00	131	165	296
11/27/15 16:00	11/27/15 17:00	159	178	337
11/27/15 17:00	11/27/15 17:00	108	131	239
11/27/15 18:00	11/27/15 19:00	124	109	233
11/27/15 19:00	11/27/15 20:00	106	84	190
11/27/15 20:00	11/27/15 21:00	64	51	115
11/27/15 21:00	11/27/15 22:00	46	46	92
11/27/15 22:00	11/27/15 23:00	42	46	88

Average daily flow for the bridge which enters Campo Giovanni e Paolo based on an average of all data collected from the camera at this location

		SGP - Bridge Entrance		
Time period start	Time period end	Traffic In	Traffic Out	Total
12:00:00 AM	1:00:00 AM	2	0	2
1:00:00 AM	2:00:00 AM	1	1	1
2:00:00 AM	3:00:00 AM	1	1	1
3:00:00 AM	4:00:00 AM	0	1	1
4:00:00 AM	5:00:00 AM	0	1	1
5:00:00 AM	6:00:00 AM	2	1	3
6:00:00 AM	7:00:00 AM	76	44	120
7:00:00 AM	8:00:00 AM	537	282	819
8:00:00 AM	9:00:00 AM	363	285	648
9:00:00 AM	10:00:00 AM	417	378	795
10:00:00 AM	11:00:00 AM	457	440	897
11:00:00 AM	12:00:00 PM	467	470	937
12:00:00 PM	1:00:00 PM	393	432	825
1:00:00 PM	2:00:00 PM	309	323	632
2:00:00 PM	3:00:00 PM	303	250	554
3:00:00 PM	4:00:00 PM	395	352	747
4:00:00 PM	5:00:00 PM	211	210	421
5:00:00 PM	6:00:00 PM	20	18	38
6:00:00 PM	7:00:00 PM	11	10	21
7:00:00 PM	8:00:00 PM	9	9	18
8:00:00 PM	9:00:00 PM	7	5	12
9:00:00 PM	10:00:00 PM	3	3	6

10:00:00 PM	11:00:00 PM	4	5	9
11:00:00 PM	12:00:00 AM	2	1	3

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