Traversing the Labyrinth:

A Comprehensive Analysis of Pedestrian Traffic in Venice

An Interactive Qualifying Project report submitted to the faculty of
WORCESTER POLYTECHNIC INSTITUTE
in partial fulfillment of the requirements for the Degree of Bachelor of Science.

Submitted on January 9, 2012 by:

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Abstract

The purpose of this project was to contribute to the development of a pedestrian model to assist the City of Venice in the management of the ever-increasing influx of tourists. To validate the model, the team quantified pedestrian traffic at bridges, gondola crossings, and waterbus stops, and also compiled data regarding demographics, public transport usage, and tourist attractions within the district of San Marco. In collaboration with the Santa Fe Complex, the team confirmed the feasibility of the model by producing a prototype that effectively simulates pedestrian mobility in the study area. To extend the model to the entire city and guarantee its long-term sustainability, the team determined that the existing networks of surveillance cameras could be leveraged to automatically feed the model in future years.

Acknowledgements

The 2011 project team would like to extend their deepest thanks to their sponsor at the Venice Department of Mobility and Transportation, Signore Loris Sartori. Without him, the project would not have been as successful or comprehensive. A special thanks goes to the City of Venice for the data that was shared with the team to extend the reach of the project, and to Ugo Bergamo, Mayor Emeritus and current Head of the Department of Mobility, for taking interest in the project outcomes. They would also like to thank the Venice project advisors, Professors Fabio Carrera and Frederick Bianchi, for their valuable input and guidance. Lastly, they would like to thank Cody Smith from the Santa Fe Complex, who provided indispensible coding knowledge in respects to the agent-based model.

Authorship

This Interactive Qualifying Project report was completed with equal contributions from each team member.

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Executive Summary

This project contributed to the development of a computer model which represents pedestrian traffic within the Venice district of San Marco. The development of a prototype confirmed that a pedestrian model for the city is feasible to create and will aid in the management of the increasing influx of tourists. The number of tourists which visit the city each year is increasing at an exponential rate, overwhelming the physical and transportation infrastructures.

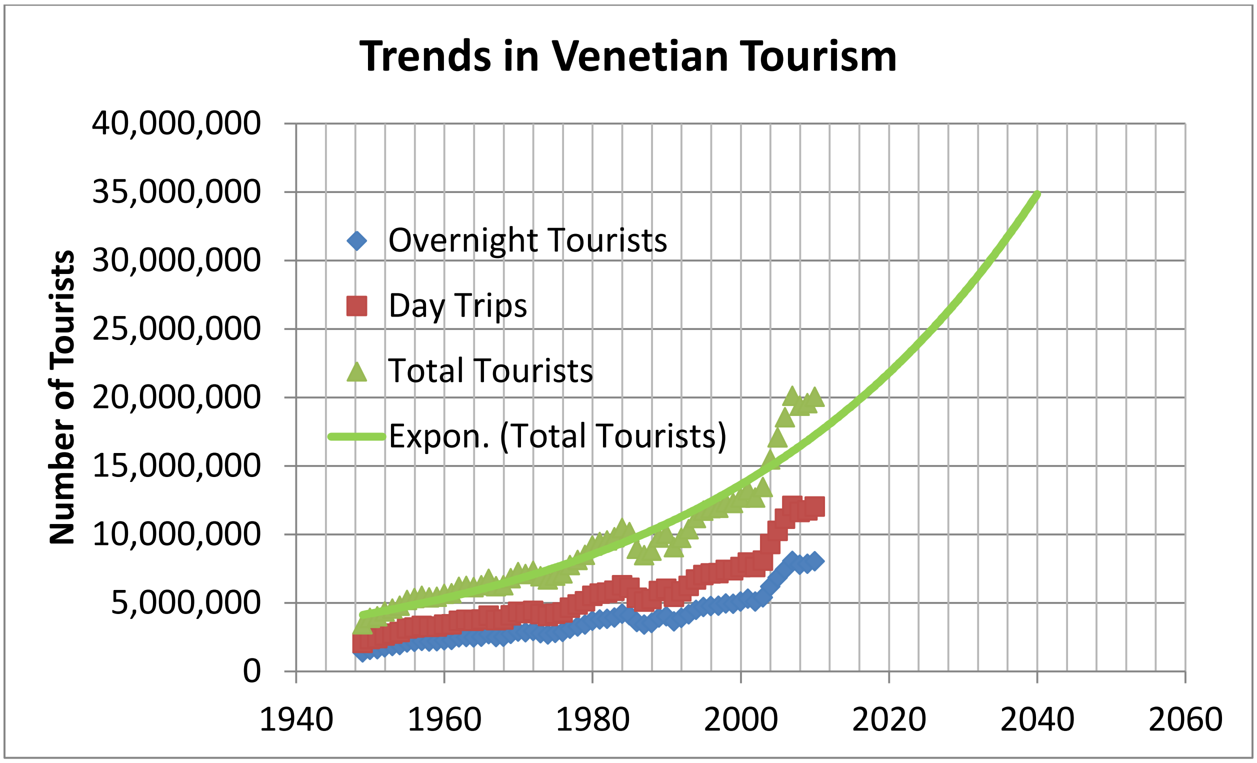

Figure 1: 60 Years of Tourism

Overcrowding becomes a large problem on days of particularly high tourism; management of traffic congestion becomes necessary through the use of preventive measures. Some of these preventive measures are temporary bridges, unidirectional walkways, deploying police to direct traffic, and installing pedestrian barriers. The development of this model for the entire city would allow for traffic predictions to occur, allowing the municipality to effectively prepare these preventive measures and alleviate congestion.

In order to ensure an accurate representation of traffic dynamics which occur within the city, data regarding lodging, transportation, and the city's demographics was collected and inputted into the model. To validate the model's accuracy, counts of pedestrians were performed at bridges and at ferries along the Grand Canal called *traghetti*.

PEDESTRIAN TRAFFIC STUDIES

By combining the findings from the field counting procedures with additional information received from Actv, the local public transportation company, the project team was able to draw an understanding of the magnitude of the flow of traffic into and out of an area within San Marco.

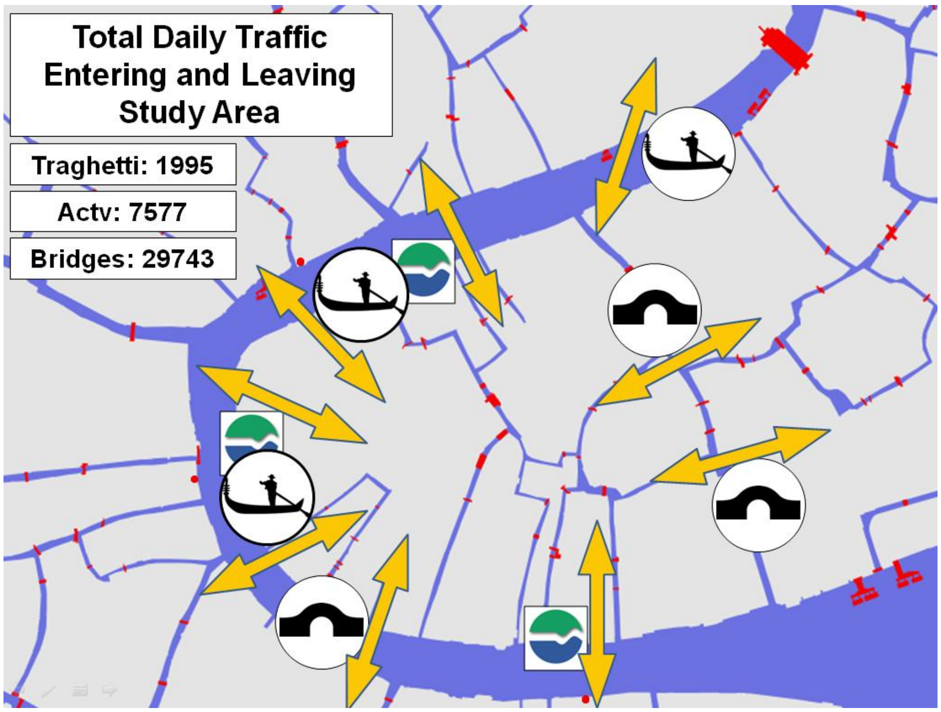

Figure 2: Total Traffic Flow

Once a higher understanding of the magnitude of traffic was achieved, hypotheses regarding how traffic flows over the course of the day were made. By comparing the number of passengers entering and exiting San Marco on waterbuses, it was found that a large number of pedestrians enter the area in the morning, and leave during the evening, especially during the hours where Venetians travel to and from work.

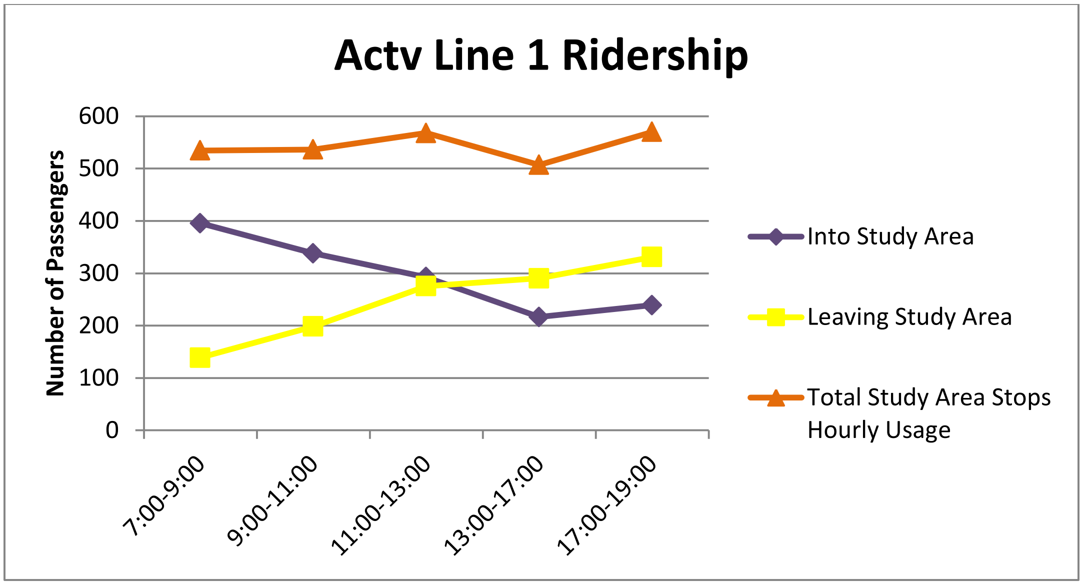

Figure 3: A Day's Line 1 Ridership – *Sant'Angelo* and *Santa Maria del Giglio* Stops

One explanation for this trend regards the district of San Marco as an area where Venetians will work and tourists will visit, but also an area with fewer residencies. This hypothesis is supported by demographic data from the most recent census. It was found that there are approximately 4.5 thousand residents living within the district of San Marco, in contrast to approximately 15 thousand jobs. Data from all these sources coincides cohesively, which allows a clearer picture to be painted about the traffic situation. The variety of compiled and collected data helps eliminate fear of discontinuity when the data sets are integrated with a computer model.

Autonomous Agent-Based Computer Model

An accurate representation of traffic flow within the city of Venice is viable by using computer programming and available data. The resulting system was made up of two components which contribute to all traffic situations. The first is the environment of the model, and the second is the pedestrians which move about this environment.

Firstly, a simulated environment which represents the city of Venice was created. The walkways which pedestrians use to move about the city and the attractions that the pedestrians visit in a day needed to be accurately represented. The environment sets the framework for the traffic situation. Next, the pedestrians were represented by entities, called agents, within the model. For the situation of Venice, the two major types of agents are residents and tourists. These two types of pedestrians behave differently and must therefore be accounted for individually.

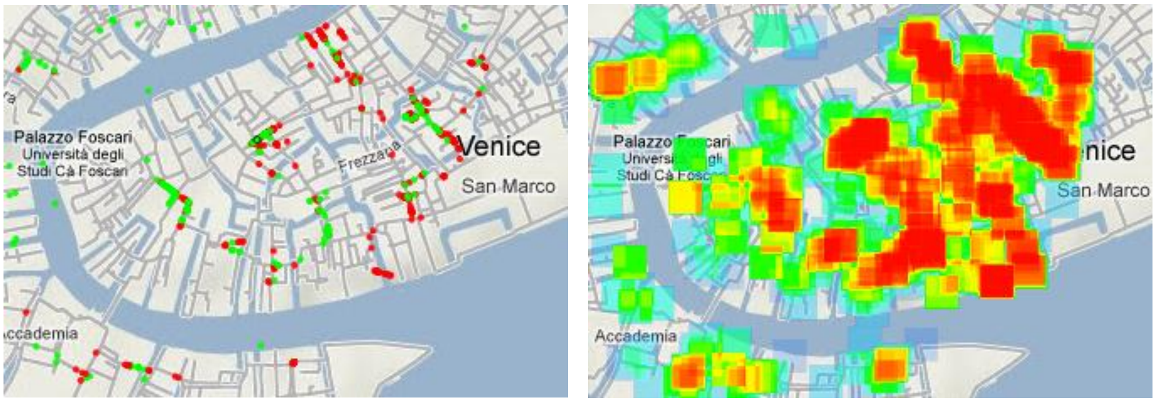

Figure 4: Displays of the Functioning Model with Agents and Heat Map Displayed

The development of an agent-based computer model served many purposes. First and foremost, it allowed for gaps in collected data to be filled, allowing for heightened awareness about the factors which influence both mobility and the development of traffic within the city. Additionally, a completed model has the ability to predict future problems regarding traffic, and allow for preventive measures to be taken to alleviate these problems. These measures will allow for mobility to be improved within the city.

CONCLUSIONS

Through the Interactive Qualifying Project process, the team has been able to come to several succinct conclusions. It was determined that a comprehensive agent-based computer model for the entire city of Venice is feasible, and could accurately portray pedestrian traffic. The model could serve two primary functions for the city of Venice. It could be used to fill gaps in current pedestrian traffic data sets and to predict future traffic scenarios within the city. The prediction capabilities of a model would enable the city of Venice to implement preventive methods of traffic control rather than reactive ones, thus allowing the maintenance of an acceptable level of traffic flow.

The project team has also concluded that the use of software video counting systems in Venice is not only feasible, but more effective than current means of manual pedestrian data collection conducted in the field. Such a system could utilize the video surveillance systems already in place throughout the city. The dual-tasking of established cameras along with the addition of cameras at key traffic chokepoints would create a system that could collect data to increase the accuracy of the model autonomously and perpetually after a one-time cost.

Through the project team's research, it was determined that because only approximately thirty percent of Actv and Alilaguna passengers validate their tickets through the Imob system, this data does not accurately portray traffic within the city. Without a method, such as the implementation of turnstiles, to guarantee ticket validation, this data should not be used in similar studies.

As Venice continues to see a rise in tourism, mobility within the city will become an even greater issue. The problem will not dissipate and will require the attention of WPI teams and the city of Venice for years to come.

1 Introduction

Around the world, growing population and urbanization has led to a constriction in the ability of an individual to move about, or a decrease in mobility. Cities worldwide are plagued with mobility issues. Many travelers try to avoid city traffic to save time on their trips, and those who cannot avoid traveling through cities must plan ahead accordingly. In an attempt to better increase mobility, urban districts adopted public transit systems in the form of buses, underground subways, trams, trains, and even boats. These systems can transport large amounts of travelers and ease the congestion that results from high usage of private transportation. Mobility issues are even more discernible in Venice, Italy because the only modes of travel are by foot or boat.

Figure 5: The Framework of Venice's Islands, Canals, and Walkways.

Venice is made up of 121 islands connected by 433 bridges[1], with no room to expand. The canals that branch off of the Grand Canal range from 3 to 10 meters in width, and the intricate network of walkways are made up of streets that average 2 meters wide. In a conference regarding tourism on November 29, 2011, the Venetian Office of Tourism reported that approximately 20 million tourists had ventured to the city during the year 2010[2]. This number of tourists has doubled since the 1980s. As illustrated in Figure 6, tourism is exponentially increasing in Venice. The infrastructure cannot

[1] http://www.comune.venezia.it/flex/cm/pages/ServeBLOB.php/L/EN/IDPagina/117
[2] Venezia, Comune Di. *Il Turismo Nel Comune Di Venezia*. Venezia: Assessorato al turismo, 2011.

expand, and is at risk of succumbing to the mass amount of pedestrians traversing the city on a daily basis.

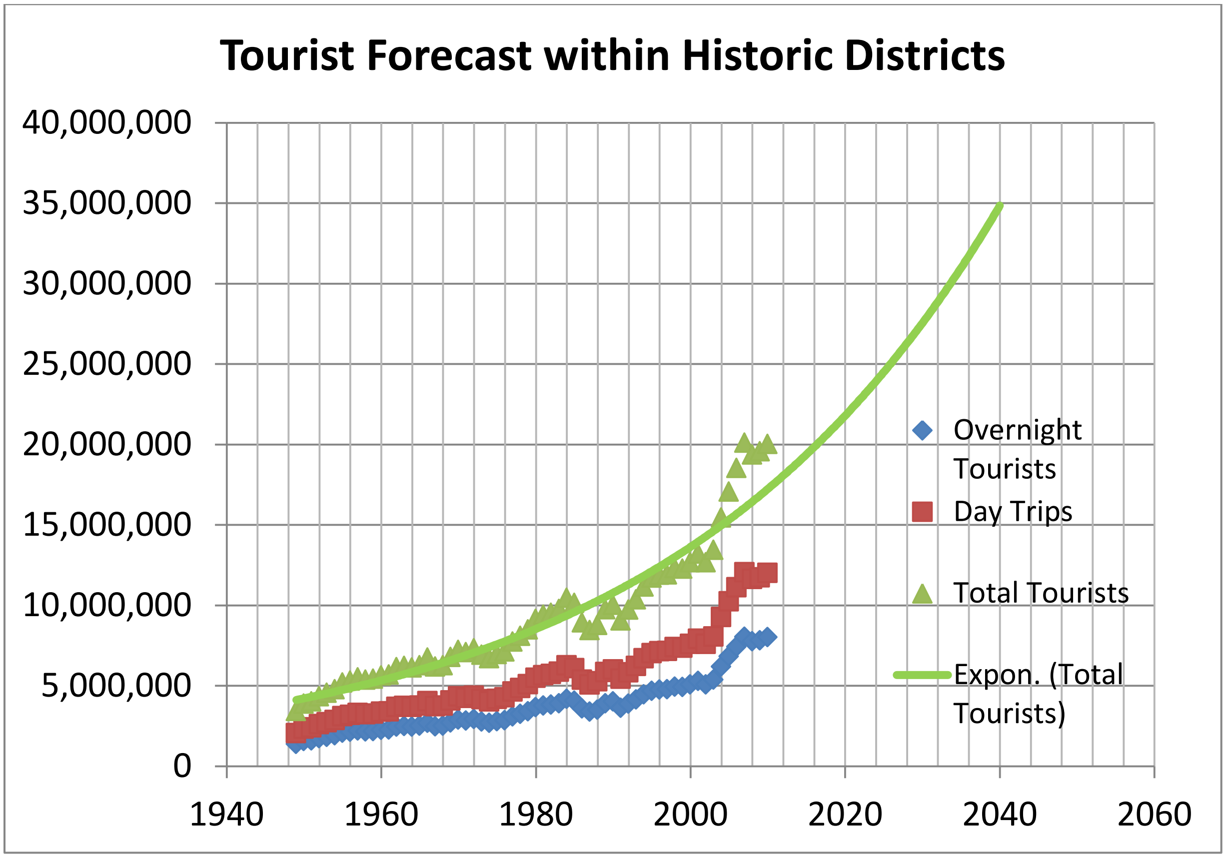

Figure 6: The Tourism Trend in Venice from 1949 to 2040

Locations that often create holdups in traffic due to narrow walkways are called choke points. Bridges are evident locations where traffic jams frequently occur in Venice, especially when tourists stop at the apex of a bridge to take pictures of the view. Pedestrians can get from island to island using the *traghetti*, ferry crossings across the Grand Canal. In addition, *Azienda del Consorzio Trasporti Veneziano* (Actv), the public boat transportation system, uses *vaporetti* to transport passengers about the entire city. These forms of boat transport have helped alleviate a portion of the overcrowding at bridges as well as facilitate the flow of water traffic by centralizing travel by watercraft through 20 routes on the canals, as seen in Figure 7.

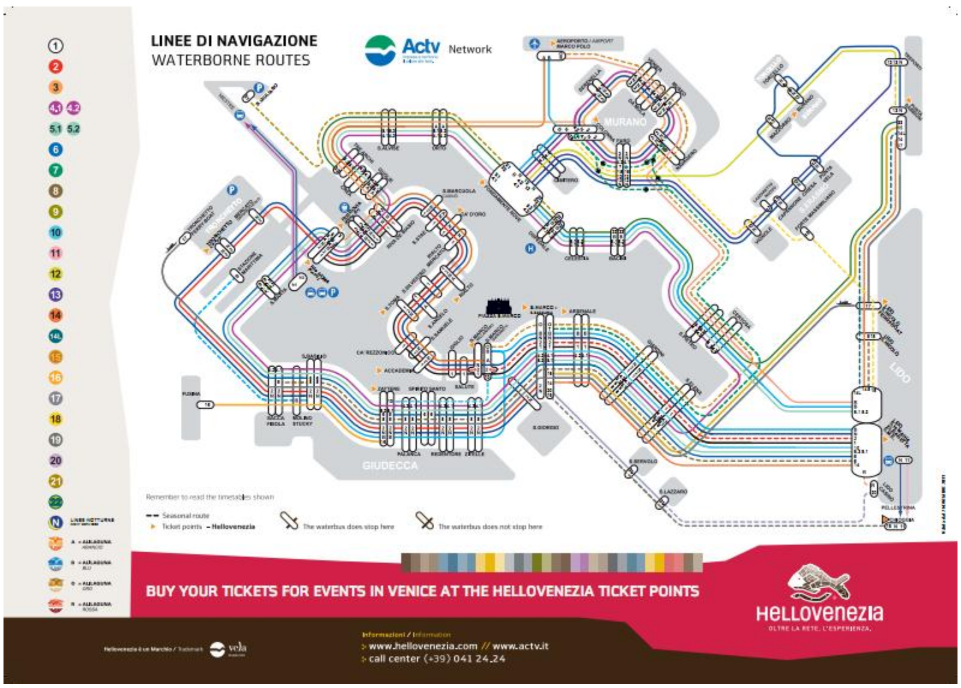

Figure 7: The Actv Public Transportation System Lines

During the Carnival and other festivals, congestion can become so severe that pedestrians come to a standstill. During these instances, the city must take preventive measures ahead of time to alleviate congested areas. These preventive measures include deploying the police to go on site and direct traffic flow, as well as temporarily making walkways or bridges unidirectional. Pedestrian barriers are used as another means to redirect traffic flow within the city. All of these measures must be planned before hand, which is only possible when severe traffic congestion occurs due to festivals and other planned events. A major problem occurs when large numbers of tourists arrive during non-holiday times. Due to the lack of preemptive knowledge, preventive measures will be more difficult to employ, and instead reactive measures are used as a last resort. One of the reactive measures taken may include the closing of *Ponte della Libertà*, the bridge which allows automobiles to enter Venice at *Piazzale Roma* from the mainland.

Figure 8: Crowded Streets Cause Traffic to Stop

For the past several years, the Worcester Polytechnic Institute (WPI) Venice Mobility Interactive Qualifying Project teams have been working with the Department of Transportation and Mobility, collecting qualitative pedestrian data with the intention of developing different means of preventing traffic issues. However, the data has not been comprehensive enough to aptly illustrate the issue of pedestrian mobility in Venice, nor has data been succesfully compiled in a centralized location.

In an attempt to combat the pedestrian traffic congestion that plagues Venice, there must be an efficient method to better understand it. There is an abundance of information available from the studies done by the commune of Venice, as well as research from WPI Interactive Qualifying Projects, but there is no tool that combines all of the data and presents it in a way that can be easily used in traffic prevention. This year's Mobility Interactive Qualifying Project and its collaborators have created an agent-based model that will eventually accomplish this throughout the entirety of Venice. In order to create a comprehensive and accurate pedestrian computer model, it would be ideal for data collection to be automated in such a way that data is continuously collected and archived.

The model itself would collect data from a multitude of sources, and combine them in such a way to model reality as accurately as possible. Once the model is created it would have the ability to predict future changes in predestrian traffic. Prior to this, many steps would need to be taken to create a platform for a computer model which accurately potrays reality. Some of the tasks this model must be able to do is distinguish between different types of pedestrians who behave differently from each other, as well as compile data from multiple sources and fill in existing gaps. Two types of pedestrians which exist within the city of Venice are the local population and tourists. Both of these pedestrian types, or agent types as they are referred to within the model, will begin their days at different locations and have different geospatial priorities as they go about their day. The next large task for the model is the acquisition of accurate and reliable data.

Currently, the city has several observational systems installed that would be advantageous for the purpose of automated pedestrian data collection. These surveillance systems include the Automatic and Remote Grand Canal Observation System (ARGOS), Hydra, and Security and Facility Expertise (SaFE), which are placed in strategic locations throughout Venice that give them the ability to allow data to be collected off of video clips that can be recorded and later played back. Currently, these observational systems are used to implement speed limit laws, and monitor pedestrians and boats for crime.

If the cameras detailed above, as well as other cameras that could be installed in the future at other tactical locations, were used to collect traffic data, the data could be collected at all times of day and all year round. Clips could also be rewound and slowed down, to make sure that observational counts were collected as accurately as possible. Counts currently done for the sake of data collection by the city are incredibly expensive and also require a large amount of manpower and time; furthermore they yield only small amounts of data with large gaps. The dual-tasking of already existing cameras would lead to a more reliable method for data collection without the expensive cost.

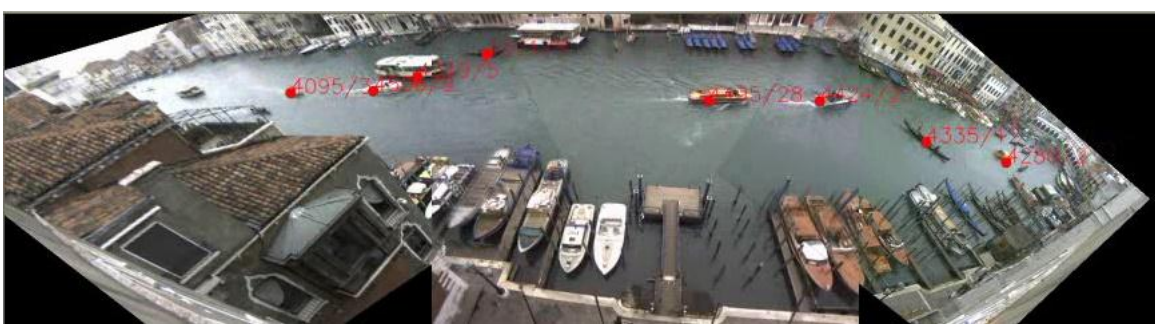

Figure 9: With the ARGOS system, live images are stitched together to generate a view of the Grand Canal. Observations are used from a multi-step Kalman filter to track targets over time[3]

[3] http://www.dis.uniroma1.it/~bloisi/segmentation/segmentation.html#ARGOS_Project

Footage collected by the many cameras within the city can later be processed by computer software, known as computer vision (CV) technology, which uses blob recognition to notice changes and movement within the field of view. The processing of this footage would lead to automated counts of the number of individuals which cross an arbitrary line created by the software. The counts produced by this software are an ideal source for reliable, accurate, data which can be collected continuously without human intervention. Furthermore, this data would have a substantial effect on the accuracy of the model.

The establishment of framework for the collection of data and development of the database for the computer model was the ambition and intent of the 2011 Mobility Interactive Qualifying Project. A structured methodology for the collecting and archiving of data has been developed and can be executed by future mobility focused projects. To continue the development of this system, this methodology has been already been conducted at key bottleneck locations throughout the district of San Marco. This data was integrated into the prototype of the agent-based computer model designed by the collaborators of this project, along with data compiled from various sources provided by the Municipality of Venice. The end goal of this project was to create the pedestrian agent-based model, which will begin to fill in gaps in data and aid in the cascade of improved mobility.

2 Background

Venice is composed of canals and narrow streets, which often impede mobility. Though the city occupies merely three square miles of land, traveling quickly and efficiently can be a challenge due to a complex network of walkways, overcrowding, and severe weather conditions. Public transportation systems attempt to alleviate pedestrian congestion, but the sheer amount of tourists visiting the city on a daily basis causes difficulty in maintaining mobility. Implementing a computer model that demonstrates how pedestrians move throughout Venice can help predict congestion locations and ultimately improve mobility.

2.1 The Mobility Infrastructure in Venice

Venice is a small city that was not meant to hold as many people as it frequently does. Venice's physical limitations cause difficulty in alleviating the congestion issues that result from the mass influx of tourists.

2.1.1 Physical Infrastructure

The physical infrastructure of Venice provides a basis for mobility throughout the city. To understand how people flow through the city, one must first grasp the foundation which allows pedestrians to move. Transportation in Venice occurs on streets, through squares, over bridges, and along canals.

2.1.1.1 Canals

The network of canals is utilized by the watercraft of the city. Both the public transportation and private boats use the same canal system, which is elaborated upon in Section 2.1.2.1. The canals separate each of the 121 islands and obstruct the continuity of streets, causing a need for bridges, a natural choke point.

Figure 10: A Canal Near the Arsenale

The canals that branch off of the Grand Canal are approximately 3 to 10 meters wide. The Grand Canal is one of the major water transportation corridors in the city; it stretches down the center of the city in a backwards S-shaped course, is approximately 3 kilometers in length, and varies between 30 and 70 meters wide[4].

2.1.1.2 Streets and Squares

There are 2,194 streets which help make up the labyrinth that is the city of Venice[5]. The streets average 2 meters in width, and the total length throughout Venice is about 157 kilometers. Every street is made up of stone or brick, and on each side are gutter stones to pass surface water or rain into conduits underneath[6]. The streets are sporadically interrupted by *campi*, or squares. There are 294 squares scattered throughout the city[7]. The streets cross the canals by means of 433 bridges, usually consisting of a single arch, with a roadway graded into low steps, connecting every island of Venice[8].

[4](Cessi, Cosgrove and Foot, Italy 2011)
[5](Morgan 1782)
[6](Morgan 1782)
[7](Morgan 1782)
[8](Morgan 1782)

Figure 11: A Standard Street in Venice

2.1.1.3 Bridges

The different islands of the archipelago are interconnected by an array of over four hundred bridges[9]. These bridges are crucial to the infrastructure of Venice, and have become recognizable as indispensable monuments of the city which are utilized on a daily basis[10]. Four of the most well-known bridges in Venice traverse the Grand Canal, including the *Ponte di Rialto*, *Ponte dell'Accademia, Ponte degli Scalzi*, and the most recent addition, the *Ponte della Costituzione*.

Figure 12: *Ponte di Rialto*

The *Ponte di Rialto* was constructed in 1588, but initially had two predecessors. In 1175 a bridge was constructed using boats for floatation to span the canal, called a pontoon bridge, in the same location as the *Ponte di Rialto*[11]. This bridge was ultimately replaced in 1265 by a fixed bridge which later collapsed[12]. The *Ponte di Rialto* remained the only location to cross the Grand Canal until 1854[13].

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9 (Davis and Marvin 2004)
10 (Contesso 2011)
11 (Contesso 2011)
12 (Contesso 2011)
13 (Contesso 2011)

Today, pedestrians can cross the Grand Canal by using one of the four bridges which now exist, in addition to the seven different *traghetti* locations.

2.1.2 Transportation Infrastructure

The transportation infrastructure of Venice provides the actual means of transit for individuals. The systems of transit serve Venetians and tourists alike throughout the year.

2.1.2.1 Public Transportation

Private boats are less common in Venice than watercraft used for shipping cargo and public transportation. This is largely due to the existence of taxi boats and a lack of space for extended docking. Taxis in Venice are multipurpose boats which not only transport clients to their desired destination but will also serve as a means of transportation for goods when not serving pedestrians. There are also other vessels which have scheduled routes throughout the city which can be used to move people between specified stops.

These forms of public transportation are one of the leading causes of boat traffic in Venice, as seen in Figure 13. Both taxis and *gondole* have random travel routes, depending on their clients' demands, and therefore become difficult to obtain data on. For example, *gondole* typically serve as sightseeing vessels for tourists and will typically slow down and make stops near points of interests[14]. These stops can cause a large amount of traffic and affect mobility. The traffic patterns of taxis and *gondole* are difficult to predict and their destinations are random, therefore their traffic patterns do not significantly influence overall mobility in Venice.

Figure 13: A Congested Canal

[14] (Chiu, Jagannath and Nodine 2002)

2.1.2.2 Pedestrian Mobility

The other prominent form of transportation in the City of Venice, travel by foot, utilizes an array of walkways and bridges. The problems associated with these walkways are derived from how the city was constructed, which led to limited space, and an increasing number of tourists which visit the city. As the city was being constructed, walkways were built to facilitate trade and commerce. Due to the significant space constrictions associated with construction on an archipelago, many buildings were constructed to the edge of the property, leaving little space for these additional walkways. This has left many of the walkways narrow, some spanning only about a meter across[15].

The stark narrowness of the walkways contributes to much of the pedestrian related traffic which occurs in the city, but it is not the only factor involved. The layout of the walkways has been compared to that of a labyrinth (as seen in Figure 14) as a result of many canals being paved over to broaden the network of walkways and alleviate traffic demands[16]. Pedestrian traffic demands have been growing perpetually since the 1950's due to the overwhelming influx of tourists[17]. The combination of a large population of tourists new to the area and a confusing layout intensifies the effects of pedestrian congestion.

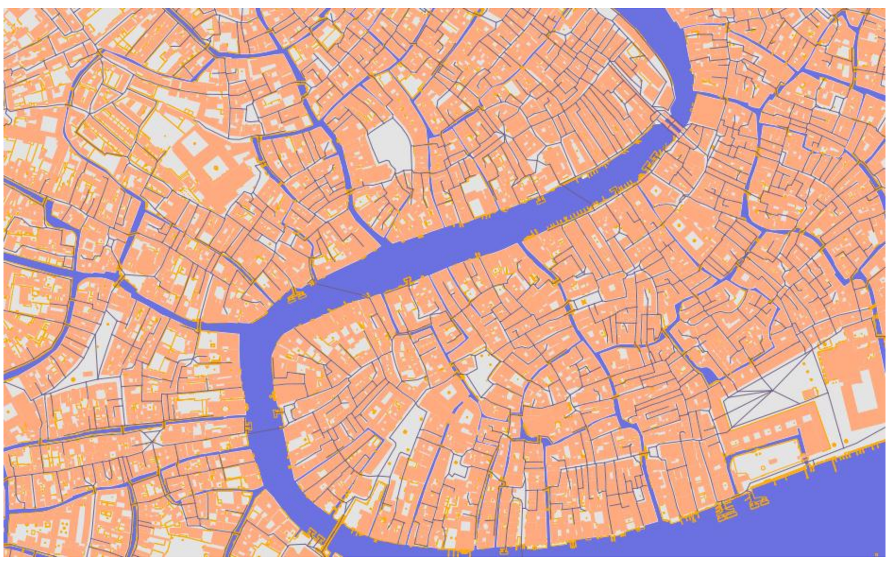

Figure 14: The Complexity of Walkways and Canals in Venice

15 (Davis and Marvin 2004)
16 (Davis and Marvin 2004)
17 (Van der Borg and Russo, Towards Sustainable Tourism in Venice 2001)

2.2 Tourism in Venice

The Queen of the Adriatic, as Venice is sometimes referred to, has been attracting foreigners for centuries, and some studies consider the city to be a mature tourist destination: one that witnesses negative environmental impacts caused by tourist congestion more frequently than other destinations[18]. The magnitude of tourists that visit Venice has a huge negative impact on the city. The resulting congestion causes mobility impairments throughout the city, and especially at popular tourist locations and during peak tourist times.

2.2.1 Tourist Attractions

The concentration of tourists is a problem that Venetians have been attempting to control for a very long time. There are a number of specific locations throughout the city that are typically visited by tourists, which creates congestion both en route to the destination and at the attraction itself. The *Piazza San Marco*, or St. Mark's square, is a popular tourist stop, where one can visit St. Mark's Basilica and bell tower. Another is the *Ponte di Rialto*, a large bridge connecting one side of the Grand Canal to the other with shops along it. A third popular destination is the Accademia Bridge and the Accademia Gallery. Together, these three destinations create what can be called the "tourist triangle," as seen in Figure 15, and it is a route that is traversed by most of the tourists visiting Venice. These destinations, as well as many other spots in Venice, are the cause of the large amount of pedestrian traffic that regularly occurs.

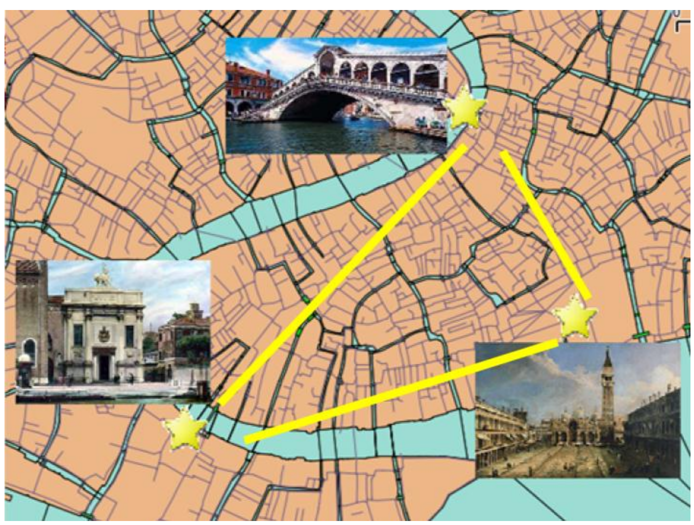

Figure 15: The Tourist Triangle

18 (Riganti and Nijkamp 2008)

Beyond the draw of the city itself, there many events held in Venice that attract a high number of tourists annually. The *Carnevale di Venezia*, or Carnival of Venice, annually takes place in February, and marks the beginning of Lent. A huge amount of tourists travels to Venice to experience the Carnival and to attend the various events held, such as the *Vogalonga*, a boat race through the Venetian lagoon, and other celebrations[19]. Events such as *Carnevale* lead to an extremely high tourist volume, which in turn causes mobility impediments for pedestrians traveling from one place to another in an efficient manner.

2.2.2 Tourism Trends

The sheer magnitude of visitors to the city creates issues within the infrastructure and affects quality of life. Traveling around the world was once reserved for only the rich or influential, but it is now a viable experience for a majority of people. This evolution towards "mass tourism" is one that is clearly seen in Venice, where there has been a significant influx of tourists over the years[20]. As the years pass, the ever-increasing inflow of tourism was predicted to exponentially increase, as seen in Figure 16. By 2040, the magnitude of tourists could reach 35 million visitors, much more than the city can manage.

[19](Carnevale di Venezia 2012 2009)

[20] (Zanini, Lando and Bellio 2008)

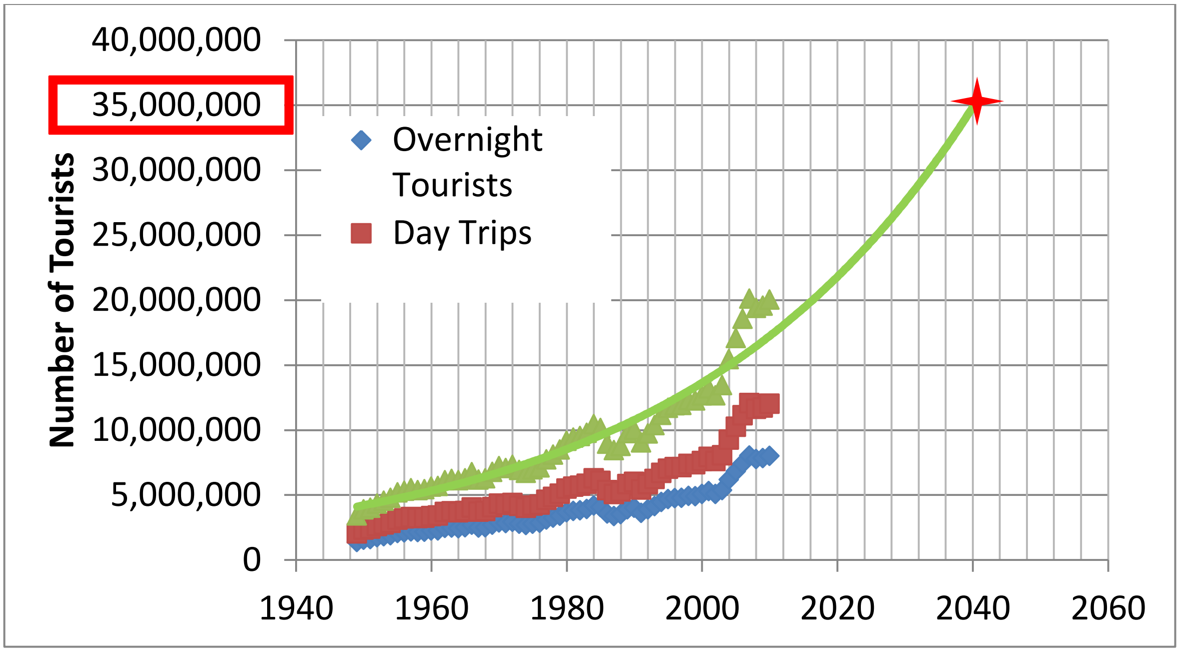

Figure 16: Graph of the Predicted Trend of Tourism

The carrying capacity of Venice, or "the maximum number of visitors the attraction can handle at a given time without either damaging its physical structure or reducing the quality of the visitors' experience" has been determined to be approximately 55 thousand tourists per day[21]. This capacity is regularly surpassed, and that leads to the ultimate issue of Venetian traffic congestion. This congestion can be seen especially during holiday and summer seasons at tourist sites and on bridges, where the limited space often creates crowds of people trying to push through to their destination. Eventually, these seasons could become the norm for everyday life in Venice and the negative effects on the city could become permanent issues.

Venice is reaching a critical point where the tourists outnumber the natives: "[w]ith its [twenty] million or more annual visitors and a local population of only around [60] thousand, historic Venice has the highest ratio of tourists to locals of any city in the world."[22] This overcrowding effect impairs and changes many aspects of life in Venice, including commuting to and from work or attempting to traverse the city for another purpose.

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21 (Van der Borg, Tourism and Urban Development: The Case of Venice, Italy 1992)
22 (Davis and Marvin 2004)

The mobility impairment created by tourism is severe, and must be addressed. The inability to traverse across the city lengthens work commutes for the employed and school commutes for students, and the condition is only expected to intensify.

2.3 Traffic Analysis Technology

Regarding future applications for collected data, the creation of an integrated pedestrian traffic model is necessary to provide an easy means of extracting useful information. Though the development of such a comprehensive model is out of reach for this year's project team given the time and fund limitations, it is important to understand pedestrian models so that data collection can be tailored to provide the model with information that is useful to its creation.

2.3.1 Agent-Based Models

The modeling approach that fits the needs of the Venice traffic model is referred to as agent-based modeling, and more specifically, autonomous agent-based modeling. This type of modeling allows for individual governing of agents, which lets each agent uniquely interact with the environment based on programmed predispositions and reactions. In modeling of traffic, each agent is assigned a specific start and end location. Though the beginning and end are predefined, the method of transportation and the path taken vary based on the interactions between the agent and its surroundings, including other agents. In terms of Venice, agent-based modeling allows for the important distinction between tourists and locals in pedestrian mobility stream models. Hence it is important to collect data that can speak to the various biases of agents, such as desire to visit a certain location during a certain timeframe.

2.3.1.1 Modeling Environment

Agents, in this case pedestrians, will interact with the Venice environment developed in the model. The environment itself is made up of two main components; edges and nodes. Edges are the borders and boundaries that define the fields in which the pedestrian agent types move. Nodes, on the other hand, are not physical or visible entities in the final 2D model. They help to define how the pedestrians will move. For instance, a specific pedestrian, depending on the constraints that are programmed into a model, will move from a node 'A' to another node 'B'. For the Venice models, these nodes are typically placed at traffic choke points like bridges. For instance, a bridge spanning a canal in an east to west direction might have a node 'A' on its east side and another node 'B' on its west side. Movement defined as 'AB' would indicate a pedestrian moving from 'A' to 'B,' or west across the bridge. Movement that is defined as 'BA' would indicate the opposite: a pedestrian traveling east across the same bridge. The movement between nodes A and B for *Ponte del Teatro* can be seen in Figure 17. Data is organized by the number and type of pedestrian, as well as their node movement at choke points.

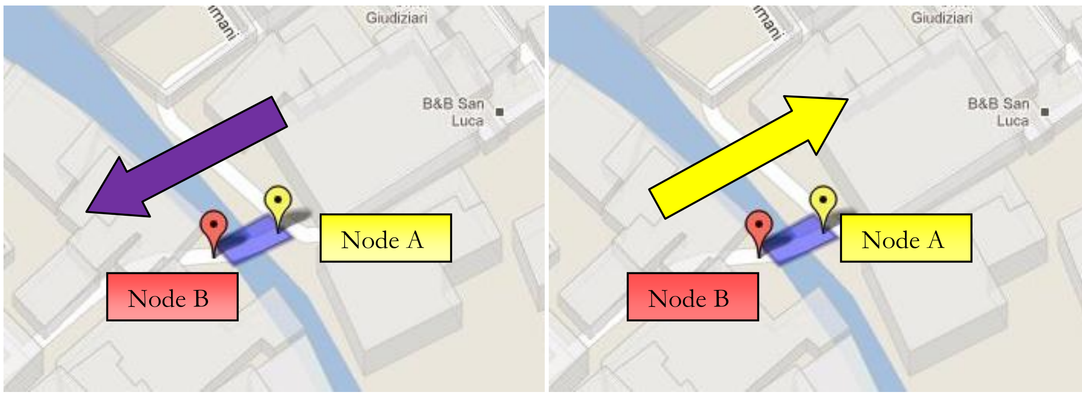


Figure 17: Movement of Pedestrians Between Nodes A and B

Nodes can also help define sources, points where pedestrians originate, and sinks, points where pedestrians are attracted. How agent types are programmed will determine their 'source-sink interaction'. In Venice, sources and sinks can be split up into two categories based on the types of pedestrians. Locals tend to originate from residential areas and will generally flow to places of employment or learning. In this case, this would mean that their homes are the sources and their places of work and schools are the sinks. At the end of the day, this would be reversed and the sources and sinks would switch. Tourists tend to originate from hotels, bus terminals, and the train station, and are attracted to places like museums, shops, and the Tourist Triangle. In the case of a museum, two nodes would still have to be used to define movement 'in' and 'out' of the museum. The museum would then be defined visually on the model so the movement in and out of the building doesn't look like pedestrians disappearing and reappearing at a point inside the model.

The concept of 'disappearing' and 'reappearing' occurs when modeling pedestrian traffic in Venice. Walking is not the sole form of transportation in the city, and many people use multiple forms of transportation throughout a day. If there is no integration between pedestrian traffic and boat traffic in the model, then when a pedestrian boards a *gondola* ferry in the model it will look as if someone disappeared from their original position and reappeared somewhere else. To combat this, data can be collected that reflects the number of pedestrians that are getting on and off at each boat stop. Nodes can then be used at each stop in the model to define movement on or off boats. A truly comprehensive Venice traffic model would completely integrate the boat and pedestrian traffic models into one because the various forms of transportation are not independent of one another.

2.3.2 Automatic Data Collection

An agent-based pedestrian computer model is an effective tool for representing traffic data and filling in data gaps, and it would be even more comprehensive if it contained data that was continuously being collected. This can be attained using several different types of technology.

2.3.2.1 Video Feeds

Several surveillance systems are currently installed in Venice for the purpose of managing boat traffic and preventing crime that are constantly running. ARGOS is the camera system run by the *vigili urbani*, or Venetian police, and it lines the Grand Canal tracking boats to ensure that speeding doesn't occur. The police also have cameras set up at Actv stops and other locations throughout the city to survey for crime and abnormal activity. SaFE is a monitoring system for the ports of Venice, and Hydra is a system used to manage and ensure safety and security of water traffic along the Giudecca Channel.

Figure 18: The SaFE Camera Network

The Venice Tide Center also has a camera system in place to monitor the tide levels in locations that receive the higher tide levels, such as St. Mark's Square (see Figure 19).

Figure 19: A Video Surveillance View of St. Mark's Square

All of the cameras that are already in place in the city could easily be used to collect data year-round and for any time of day. Footage could even be played back to ensure accuracy in data collection. Utilizing the surveillance systems already in place for data collection would only improve the pedestrian model's accuracy.

2.3.2.2 Programming Software

Traffic models are very useful tool for understanding and improving mobility streams. To make the pedestrian model even more automated, the implementation of autonomous data collection software would allow for continuous collection of data with minimal human interaction. Open CV is a software approach that uses video to autonomously recognize, track, and record traffic, as well as distinguish physical difference and record velocity.

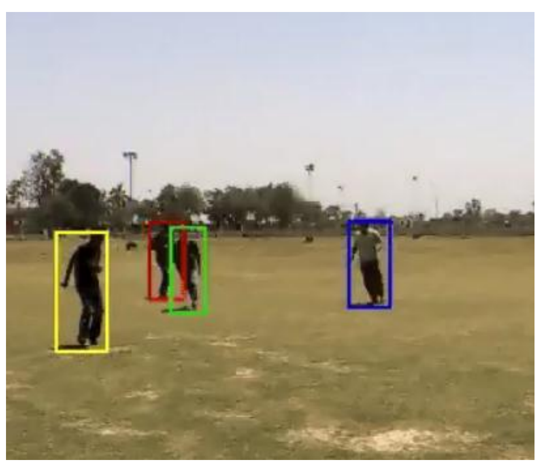


Figure 20: An Example of a Functioning Open CV Model

If Open CV software was installed into a computer security system connected to the existing video surveillance systems in Venice, data could be collected continuously, pace could be recorded, and there could be a distinction between pedestrian types. All of this would further the comprehensiveness of the model.

3 Methodology

The mission of this project was to collect pedestrian traffic data for the end goal of developing an agent-based modeling system that collects and archives data to effectively predict the behavior of pedestrian mobility streams in Venice.

Project Objectives:

1. To quantify pedestrian traffic at key locations
2. To analyze the feasibility of using video based pedestrian traffic counting techniques
3. To organize the pedestrian traffic data into a format capable of helping develop a pedestrian agent-based model

This project focused on pedestrian movement throughout the district of San Marco in Venice, Italy, as seen in Figure 21. A methodology was developed for accurately counting pedestrians and the feasibility of using video feeds to count pedestrians was investigated. The data that was collected was integrated into an agent-based model developed by the team's collaborators. Using real time pedestrian counts ensured that the walkers in the model had appropriate timing and destinations. Employing the methodologies that have been developed during this project in future years for the other five districts of Venice will ensure a greater understanding of pedestrian movement in the city.

The project occurred from August to December of 2011, with preparatory work during the first 8-week term and on site work throughout the latter 8 weeks. The project was limited to gathering data concerning pedestrian congestion, taking into account only the predetermined agent typology. To accomplish this, pedestrians were quantified based on direction of movement and whether the pedestrian was a Venetian or tourist.

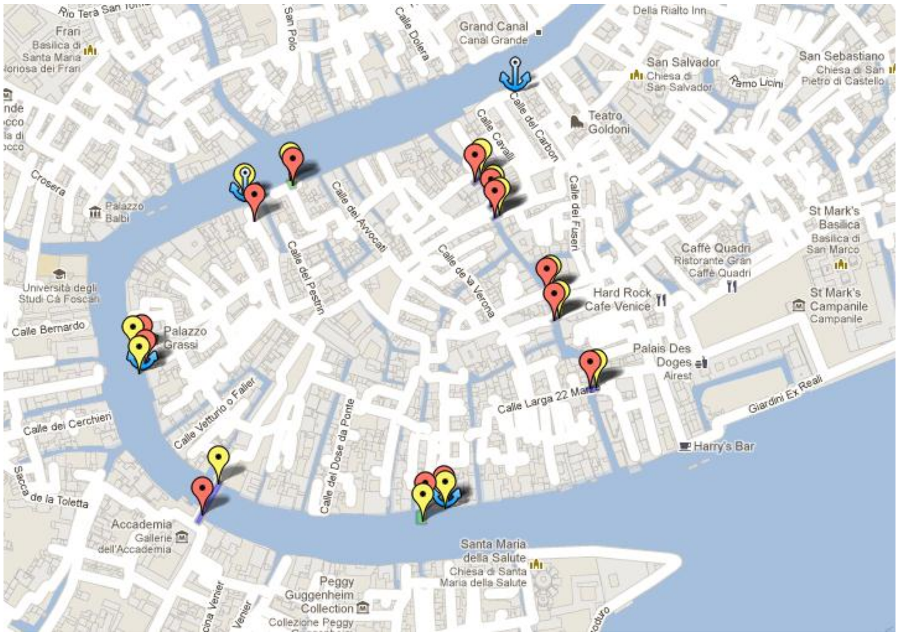


Figure 21: Area of Study Map

3.1 Quantifying Pedestrian Agents

To accomplish the project objectives, the project team counted pedestrians at key locations in the area of study. This data was then collected and integrated into a computer model for traffic analysis. To do this, a specific counting method was developed to conduct manual counts based on direction of flow and pedestrian type at key connection points around San Marco. This counting method could be used by future teams in order to ensure consistent data sets.

3.1.1 Focus Area and Key Counting Locations

The 2010 Venice project team previously analyzed congestion in the San Marco district at ten bridge locations, as seen in Figure 22[23]. The 2011 project team focused on different counting locations for the purpose of creating a distinct location for the starting point of the computer model within the San Marco district. The Accademia Bridge was the only bridge in common between the two collection years.

[23] Amilicar, Marcus, Amy Bourgeois, Savonne Setalsingh, and Matthew Tassinari. *Mobility in the Floating City: A Study of Pedestrian Transportation*. Worcester: Worcester Polytechnic Institute, 2010.

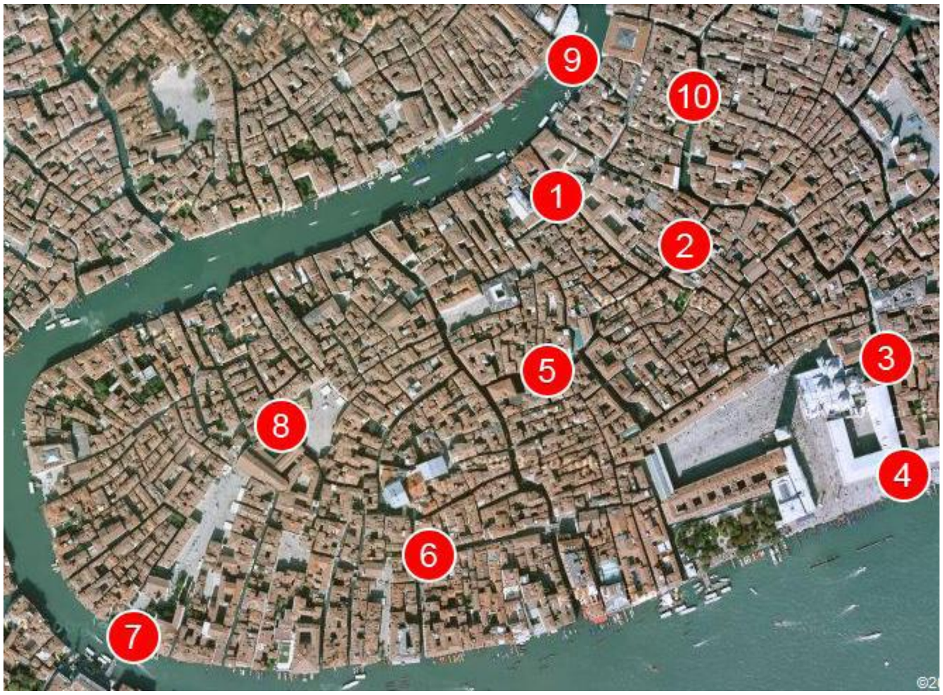


Figure 22: Map of the Ten Counting Locations Used by the B'10 Team

After evaluating a map of the area, the counting locations were determined to take place at the six bridges that connect the two sections of land divided by the *Rio San Luca*, *Rio del Barcaroli*, and *Rio San Moisè*. It was also concluded that, because *Ponte dell'Accademia* is the only bridge on the Grand Canal that leads into the western part of the San Marco district, it should also be analyzed by the team. Counts were performed at the four *traghetto* stops in the district along the Grand Canal. These eleven counting locations covered all locations for pedestrians on foot entering and exiting the western half of the San Marco district. The complete list of bridges and *traghetto* stops are referenced in Table 1, and the map of each of these is seen in Figure 23.

Table 1: Bridges and *Traghetto* Stops in the Study Area

Study Area Bridges	Study Area *Traghetto* Stops
Ponte del Teatro	*Riva del Carbòn – Fondamente del Vin*
Ponte de San Paternian	*Sant'Angelo – San Tomà*
Ponte de la Cortesia	*San Samuele – Ca'Rezzonico*
Ponte dei Barcaroli o del Cuoridoro	*Campo del Traghetto – Calle Lanza*
Ponte de Piscina	
Ponte San Moisè	
Ponte dell'Accademia	

Figure 23: Google Map of *Traghetto* Locations and Bridges Locations. Blue Anchors Symbolize *Traghetti* Stops and Red and Yellow Marker Pairs Symbolize Bridge Locations

3.1.2 Distinguishing Between Agent Types

A useful feature of the pedestrian model is the distinction between pedestrian agent types, such as Venetians and tourists, because each type of pedestrian behaves differently. A flow chart of the breakdown of the different pedestrian types can be seen in Appendix B. Venetians have a structured schedule that occurs daily. During the workweek, Venetian pedestrians leave their residence to go to the market, work, or school. The route traveled by locals is usually predetermined to account for the shortest path and time. Tourists are often random in their routes, and travel in a "wandering" pattern. Major tourist sites are often destinations, but they may stop at a shop or restaurant on the way. As a result, tourist movement is less structured. In order to reflect the different behaviors in the agent-based computer model, it was important to collect data based on the type of pedestrian.

The individuals that were on-site conducting the counts distinguished pedestrians mainly based on visual cues. As previously mentioned, Venetians had more of a direct route, so their pace was steadier, while tourists had more of a random behavior. Locals often walked with pets or pulled dollies; and businessmen and women or employees were dressed in business attire. Tourists were singled out by whether or not they were holding cameras, or if they were in tourist groups led by a guide. They were more likely to wear leisurely clothing. A complete list of the classifications used is in Table 2.

Table 2: Agent Type Indicators

Tourists	Venetians
"Wandering," slow walking pattern	More direct, fast walking pattern
Carries a camera or takes pictures	Business or uniform attire
Led by a tour guide	Briefcase or cart
Does not speak Italian	Walking a pet
Window shops	
Looks at a map	

3.1.3 Counting Method

In order to accurately quantify the flux of pedestrians at bottleneck locations the team utilized a specific counting method, which allowed a quick and efficient method of counting a large number of pedestrians. Once the peak times were discovered (when pedestrian mobility is at its heaviest), manual counts were conducted in the field based on direction of flow.

Individuals were stationed at each bridge in clear view of pedestrian flow with mechanical counters in each hand. Each clicker represented a direction of flow. For example, the clicker in the individual's left hand represented pedestrians moving away from the counter, and the clicker in the individual's right hand represented pedestrians moving towards the counter. For fifteen-minute intervals, the individual would click for each pedestrian that crossed the bridge and in which direction he or she moved. Each individual determined a node on the bridge, and clicked for each person to cross that node. For consistency, children being carried by their parent or in carriages, and dogs and other pets were not counted.

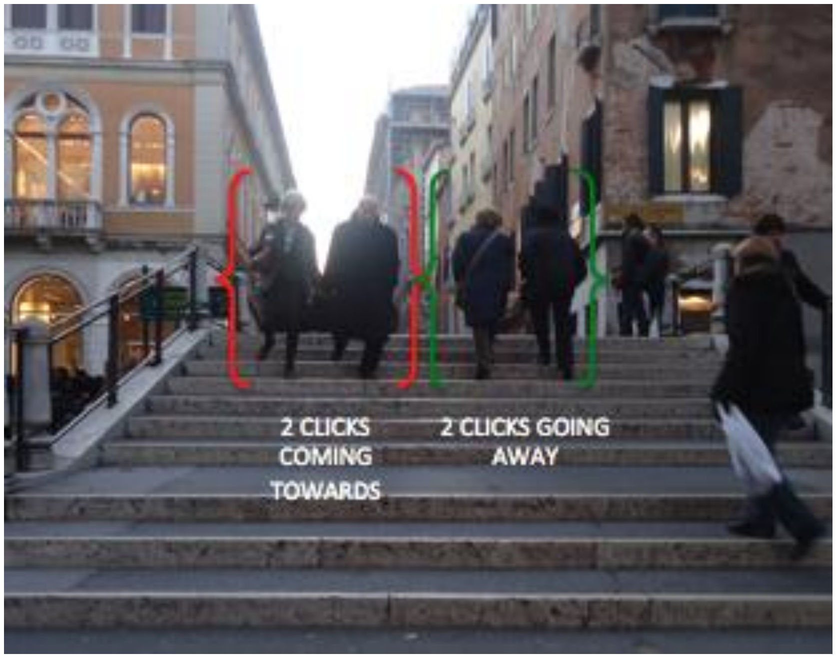


Figure 24: Example of Counting Based on Direction on *Ponte San Moisè*

At the end of each fifteen minute interval, the number read on the clicker was recorded into a field form (see Appendix D) which was later placed into spreadsheets to be submitted for integration into the agent-based computer model.

If flow at the peak time was determined to be too heavy for one individual to count, then two individuals were stationed at that location and each individual counted only one direction of flow. This ensured the accuracy of the data collected.

To determine the volume of tourists utilizing a specific bridge on any given day, three project members counted tourists while one project member counted total flow for 15-minute intervals for two-hour blocks during the peak volume time. The tourist counts were averaged to account for outliers (if one team member identified a significantly larger or smaller number of tourists) and recorded in database forms. A percentage of tourist attendance at each bridge was calculated by dividing the average by the total number of pedestrians. These percentages were applied to the rest of the bridge data collected by the 2011 project team and can be seen in Appendix G

The 2010 team performed preliminary field counting to determine the limit of one counter, and found that one counter was capable of recording one direction of flow while distinguishing between Venetian and tourist without being overwhelmed. Their team decided that two counters per location, one per direction, were necessary to reduce the risk of data loss. If a certain time or location was anticipated to have unusually high traffic volumes, the decision was made as to whether or not more than two counters would be stationed at that location. Additionally, to verify the efficiency of the 2011 model and the accuracy of the on location counts, this year's team employed the same form for our video recording counts which are discussed further in Section 3.2.

The counts made by each individual were then collaborated at the end of the time bracket and collected in Excel spreadsheets that were submitted to the collaborators at Santa Fe Complex and integrated into the pedestrian computer model. This data was also converted into a format visible on GIS Cloud for still-time visualizations. Refer to the following Section 3.1.6 for the details on the data collection forms.

3.1.4 Quantifying *Traghetti* Passengers

The same method for direction-based counting was used for counting at *traghetti* stops. A clicker in each hand represented the direction of traffic traveling into or out of the study area. The time of when the boat arrived and departed each stop was recorded along with the number of passengers that got on or off the boat. The field form for *traghetti* counts can be viewed in Section 3.1.6 in Table 6.

3.1.5 Schedule for Performing Field Counts

For the purpose of having consistent data for a comprehensive computer model of pedestrian flow, the project team counted at specific times of day.

3.1.5.1 Bridge Field Count Time Schedule

After determining the peak volume times of and which bridges contained the majority of traffic (as seen in Section 3.1.3), it was decided that these times would be the best to conduct counts for the model. While data from all times of day would be most ideal, due to the time limitation of seven weeks, the team sought the most crucial data for the framework of the model.

The team decided that the best time to conduct counts was late afternoon into the early evening, when most people were retiring home from work or most tourists were ending their days or going to dinner. Therefore, a weekly schedule for counting was devised, as seen in Table 3.

Table 3: Schedule for Bridge Counts

Bridge	Weekday	Weekend
Ponte de la Cortesia	15:30 – 18:30	15:30 – 18:30
Ponte San Moisè	15:30 – 18:30	15:30 – 18:30
Ponte dell'Accademia	15:30 – 18:30	15:30 – 18:30

3.1.5.2 *Traghetti* Field Count Time Schedule

Traghetto stops ran on strict operation schedules, so time brackets for these counts were developed in order to cover all hours of operation for each stop. Table 4 shows the operational hours for each *traghetti* stop in the 2011 study area.

Table 4: Schedule for *Traghetto* Stops

Traghetti Stop	Monday – Saturday	Sunday
Riva del Carbòn – Fondamente del Vin	8:00 – 13:00	8:00 – 13:00
Sant'Angelo – San Tomà	7:30 – 20:00	8:30 – 19:30
San Samuele – Ca'Rezzonico	8:30 – 13:30	Closed
Campo del Traghetto – Calle Lanza	9:00 – 18:00	9:00 – 18:00

The *Campo del Traghetto* to *Calle Lanza traghetto* stop was closed for work while the team was taking counts; therefore no data was collected for that stop.

3.1.6 Database Forms

After conducting field counts, the data had to be compiled in one form that was readable for the computer model. To do this, the project team used database spreadsheets. An example of a database form for a bridge can be seen in Table 5. Table 6 demonstrates a *traghetti* database form. These forms only contained information that was relevant to the model, such as the time of the count, the quantity, direction, and agent type if applicable. There were different forms for each collection location and date of collection to avoid confusion within the spreadsheets.

Table 5: Database Form for *Ponte de la Cortesia* on November 2

Time	EF	FE	Total
7:00	13	17	30
7:15	22	26	48
7:30	52	41	93
7:45	49	91	140
8:00	65	65	130

Table 6: Database Form for the *Sant'Angelo traghetti* Stop on November 8

Arrival Time	Passengers Arrived	Departure Time	Passengers Departed
11:02	9	11:05	11
11:09	12	11:12	12
11:15	13	11:18	6
11:21	12	11:24	8
11:26	13	11:29	5

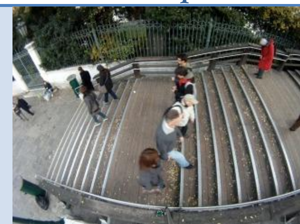
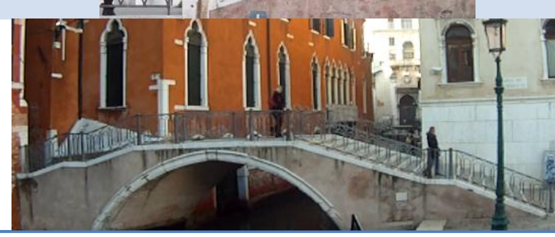
3.2 Determining Video Surveillance Feasibility

To provide an accurate computer traffic model for the city of Venice, a 'proof of concept' was developed in order to test the feasibility of using a video surveillance system to collect pedestrian traffic data. The goal of the proof of concept for the project team was to provide a variety of video-feed samples that represented the complexity and variety of pedestrian traffic in Venice. These video feeds provided an appropriate and comprehensive dataset to test the feasibility of using remote counting techniques coupled with video surveillance feeds as an alternative to manual field counts.

3.2.1 Filming Scenarios

The collected video feeds were each fifteen minutes in length to provide continuity among pedestrian traffic data. The feeds covered a variety of scenarios often seen in Venice so that the proof of concept could reflect the range of possible scenarios. The variety of camera feeds also demonstrated several different camera angles and orientations. The various orientations served to provide a means to determine which camera orientations provided a viable frame of reference for software and video based manual counts. The scenarios that feeds were collected for are shown in Table 7 below.

Table 7: Camera Angles and Traffic Flow

Camera Angles	Scenario	Example
Bird's Eye View	High Volume of Traffic (Day Time)	
Bird's Eye View	Low Volume of Traffic (Day Time)	
Bird's Eye View	High Volume of Traffic (Night Time)	
Bird's Eye View	Low Volume of Traffic (Night Time)	
Horizontal Straight On (Directly facing the traffic flow)	High Volume of Traffic	
Horizontal Straight On (Directly facing the traffic flow)	Low Volume of Traffic	
Horizontal Perpendicular (Facing perpendicularly to the traffic flow)	High Volume of Traffic	
Horizontal Perpendicular (Facing perpendicularly to the traffic flow)	Low Volume of Traffic	

3.2.2 Camera Set Up

To collect video feeds at bridges, a GoPro™ HD Hero Camera was used. For the 'Horizontal Straight On' and Horizontal Perpendicular' camera angles the camera was set up using a simple tripod. The tripod was placed in a spot where it could collect the video feed and not impede traffic.

For the 'Bird's Eye View' camera angle, the camera was attached to a 12 foot boom measured from the base of the rigging apparatus (rig). The rig was then securely fixed to the side of the bridge being counted using an industrial grade strap. Additional lashings were tied using 1/8 inch rigging line to provide extra stability and ensure structural integrity throughout the recording process. The rig was attached in such a spot so that it would not impede traffic but would still provide a bird's eye view of the spot on the bridge where there was the most constant flow and width was minimal. These spots directly correspond to assigned nodes on the Study Area map. The camera lens was aimed parallel to traffic flow.

All of the camera angles used the 'r4' video resolution mode on the HD *Hero* camera. This setting provided the most vertical viewing area with the maximum overall view. The video was collected in HD 960p resolution.

3.2.3 Statistical Comparison of Manual Counting Methods

Once collected, the video feeds could be counted remotely and then used to verify the field counts that were conducted simultaneously with the collection of the video feeds. Remote counts were conducted using the video by analyzing the feed frame by frame. This process was conducted to give what could qualitatively be considered the most accurate count. This assumption was made based on the fact that in remote counting, time is no longer a factor, as is the case with field counts. In field counting the counter only gets one chance to collect an accurate data set, but in remote counting the counter gets as many tries as necessary and can even conduct multiple counts to complete a statistical analysis if necessary. The remote video counts were then compared to the field counts to determine how precise the two counting methods are.

3.3 Analyzing and Visualizing Collected Data

To provide a streamlined method of inputting data from the field into the final model, all the data was reorganized into database forms. These forms contained a format which was cohesive with the programming of the model. In addition, these forms would allow for the bridge counts to act as a verification method that the final model is indeed accurate once completed. The reformatting consisted of organizing and explaining data in terms of nodes, or geographical points which have the ability to store parameters within them. These nodes exist for both locations, which serve as sources of pedestrian flow, as well as attractors, or pedestrian destinations. In addition, information was acquired from various alternate sources, including field counts from past years, as well as the Venice Census Statistics Office.

3.3.1 Nodular Formatting

To ensure that the agent-based model was performing as anticipated, the team came up with a usable format for tabulating the collected data for the programming requirements of the collaborators. Nodes, the location based entities or geospatial points in our model environment necessary for directing traffic flow accordingly, were created on the study area map, based on nodes already in existence from past studies. These nodes would aid in the directional flow of pedestrian traffic within the model, creating constrictions on how many pedestrians travel from one location to another. Within the model, nodes exist exclusively along pathways, and as a series of points defined as 'edges,' which the agents use as the pathways themselves. Nodes within the model each are titled by a number of approximately five digits in length, and contain many parameters which determine how many pedestrians cross daily, have already crossed, and will cross in the future. In order to simplify this nodular premise during field counts, key nodes of study were given simpler letter-based names. For example, a pedestrian crossing *Ponte San Moisè*, could cross from node L on one side of the bridge, to node K, and head towards the *Ponte dell'Accademia*, for visa versa for the direction of the *Piazza San Marco*. Nodes were also created for locations such as residential areas, places of work, schools, and areas which to tend to attract short-term visitors because these are pertinent to the creation of the most accurate model possible. Much of the information regarding these sources and attractors was based off of data received from the Census Statistics Office.

The parameters within the nodes define the majority of the functions of the model. For example, nodes have certain elements within them that define what types of people venture to them, based on algorithms that define 'nodular attraction'.

3.3.2 Rules of Attraction

For the purpose of programming, the most useful format for the data within these spreadsheets was to leave the data in its rawest form, as the counts themselves, in addition to determining the ratio of local and visiting population which frequent these nodes daily. The model originally contained random walkers which were then constricted by different rules for each agent type. These rules contain nodular attraction which, based on a probability, would draw or repel pedestrians. In addition, rules were added to create the chronologic effect of a typical day within the city. This included having pedestrians wake up at various times in the morning at their source node, travel to their respective destinations throughout the day, and end at the same source at various times during the evening. For example, the average 40-year-old Venetian would awake early in the morning and take a direct route to his or her place of labor, spend time there until travelling home, when they may run errands and stop at markets or other stores on their way back to their residence. Tourists would likely behave much differently, starting their day later, either at an entrance to the city of Venice or a lodging facility, and travel for much of the day, wandering between various sites, and finally returning to their point of origin. Each location node would have a different attractive force on each of the two agent types.

This force of attraction, which was defined as F_A, required multiple parameters to be considered in order to accurately model reality. These parameters included the individual's desire to venture to a destination, as well as the individual's distance from that destination. Similarly, the electromagnetic attraction and repulsion between subatomic particles is defined by two parameters, including distance and charge. By relating the criteria of desire to electromagnetic charge, a formula which defines F_A in a similar manner as Coulomb's Law was used.

$$F = k_e \frac{q_1 q_2}{r^2}$$

Equation 1: Coulomb's Law

In order to ensure an accurate number of each agent type arrived at every destination in the model, the "charge" of the location node was determined based on a ratio of how many people had already arrived versus the number of people which frequent that destination. This ratio constantly changed throughout the day and existed simultaneously for each location. For modeling purposes, each node then required data to define the number of daily Venetians, daily tourists, and continuously calculate the number of Venetians arrived, and tourists arrived. Furthermore, the two ratios would also exist as follows:

$$A_V = Attraction_{Venetian} = 1 - \frac{Venetians\ Arrived}{Daily\ Venetians}$$

Equation 2: Venetian Attraction Ratio

$$A_T = Attraction_{Tourist} = 1 - \frac{Tourists\ Arrived}{Daily\ Tourists}$$

Equation 3: Tourist Attraction Ratio

These two equations explain how, for the purpose of the model, the relationship between the attractive strength of a node had a negative correlation to the arrival of pedestrians. Furthermore, the attractive force, F_A, was also modified by distance. To accommodate this, the r^2 value was determined by the relative distance between the pedestrian and destination, based on the route of travel. This was important to implement because a tourist that wishes to go sight-seeing is more likely to go first to destinations that are both desirable as well as in the vicinity. After combining all these elements, the final equations which describe the relationships between each node and agent are as follows:

$$F_A = k_v \frac{A_V}{r^2} \ \ or \ \ F_A = \frac{k_T A_T}{r^2}$$

Equation 4: Force of Attraction

In order to implement all the data collected during field counts, which led to the development of the daily pedestrian statistics, Excel spreadsheets were submitted to our collaborators. These spreadsheets, by utilizing these nodular locations and the relationships described, were integrated into the pedestrian model in a format compatible with the programming language HTML5, which was used to create the model.

3.3.3 Census Tracts and Statistical Data

The remaining nodes within the area of study required additional data not provided by pedestrian counts. These nodes included many destinations of the model, such as places of work, as well as sources, such as residencies and various types of lodging facilities. In order to fulfill the requirements of the model and create probability data to appease the rules of agent attraction, the parameter which describes the total number of daily attendees needed to be discovered.

Fortunately, census tracts are publicly available by request, and have the added precision of breaking the city down, not only by its districts, but also into almost four-thousand sections. This sectional breakdown allowed for a much more precise organization of data. These tracts contain information regarding the population, with gender and age breakdown, as well as the quantity of both residencies and businesses which exist in each section. This supplementary data was organized into a spreadsheet form in order to apply it to the pedestrian model, where it would satisfy the remaining parameters for determining the attractive strengths of many locations, as well as the number of Venetian agents which would start and end their day in each particular section. In order to create a more accurate model, the ages of the local citizens was taken into account, and based on observation, would behave differently in regards to travel. For example, a resident between the ages of 15 and 19 was likely to attend school in the morning, whereas a Venetian of twice that age would be travelling to a place of occupation.

4 Results and Analysis

After data was collected at key transportation locations, the data was analyzed, and trends were discovered. The data that was compiled from sources such as the Venice Statistics Office was also included in this analysis.

4.1 Compiled Data

The data that was not physically collected by the 2011 project team was compiled from multiple sources. It was included in the computer model to create a more comprehensive view of pedestrian mobility in Venice. The data included residence and employment locations, tourist attraction attendance, and public transportation ridership.

4.1.1 Demographics

Demographic data, or statistical information concerning a population, was acquired and compiled from the Venice Statistics Office. This data allowed the project team to analyze the routes that pedestrians took throughout San Marco.

4.1.1.1 Census Tracts

Data regarding the population of the city of Venice was determined to be vital in order to ensure the computer model produced was as accurate as possible. This data would answer the fundamental questions underlying the agents modeled, including "who is being modeled," in addition to "how many?" The data from the Venice Statistics Office was organized into spreadsheets and contained information for specific regions of the city of Venice. Within the spreadsheets was valuable information regarding details about the population of the city, including the number of males, females, employed individuals, number of firms or businesses, as well as an age breakdown of intervals of five years.

This data was extremely important in creating properties for the project team's virtual environment, as well as mapping out origins and destinations for the local population. Below is a GIS layer, which indicates the number of residencies within each given tract, or section, of the district of San Marco.

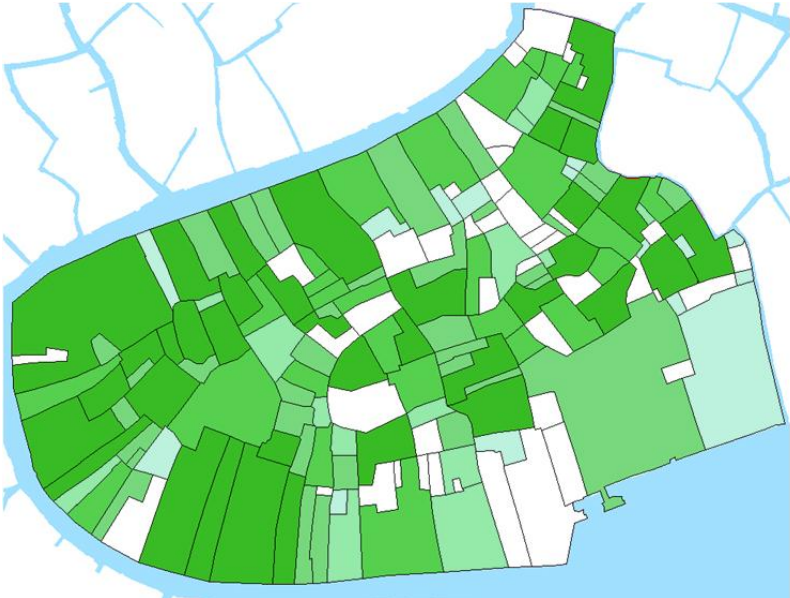


Figure 25: San Marco Residencies

In this diagram, the different gradients signify different numbers of residencies within them. Specifically, darker variants of green have a greater number, with the darkest having between 26 and 113 residencies. Areas white in color have no residencies within them. Similar evaluation was conducted in regards to the number of businesses within each section of the district of San Marco, as shown in the figure below.

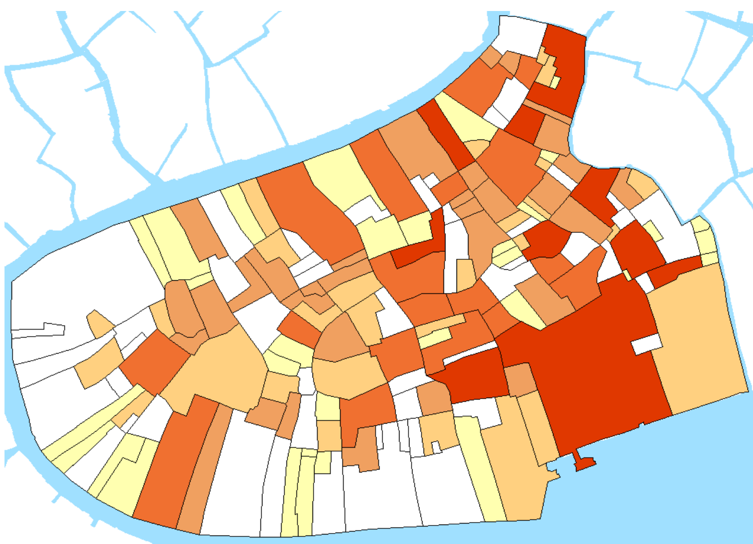


Figure 26: Employers Within San Marco

Though this census data gives a better understanding of how the local residents might move around within the district of San Marco, there are also a number of factors left unexplained to this point. To better understand the movement of the local Venetian population, those which commute into and out of this district for the purpose of work must also be accounted for.

4.1.1.2 Hotels and Tourism

Tourists who venture to Venice for just one day make up approximately 60% of the annual tourist population. The remainder of the city's visitors stays for longer periods of time and must find some sort of lodging to reside in each night. There are a number of different options available for tourists when choosing a source of accommodation for the evening, including hotels, hostels, and bed & breakfasts.

Of the available lodging establishments within the city, approximately 75% of the beds available are found in hotels, with a total of nearly 20 thousand beds across the city for the purpose of tourist accommodation. The data regarding lodging usage by tourists is available to the public by request. This fact was taken advantage of for the purpose of compiling recent hotel data to determine where overnight tourists begin and end their day. A map contrasting the difference in the number of hotels in Venice in the years 1999 and 2008 can be seen below. It is important to note that the lodging capacity of these establishments doubled within this period[24].

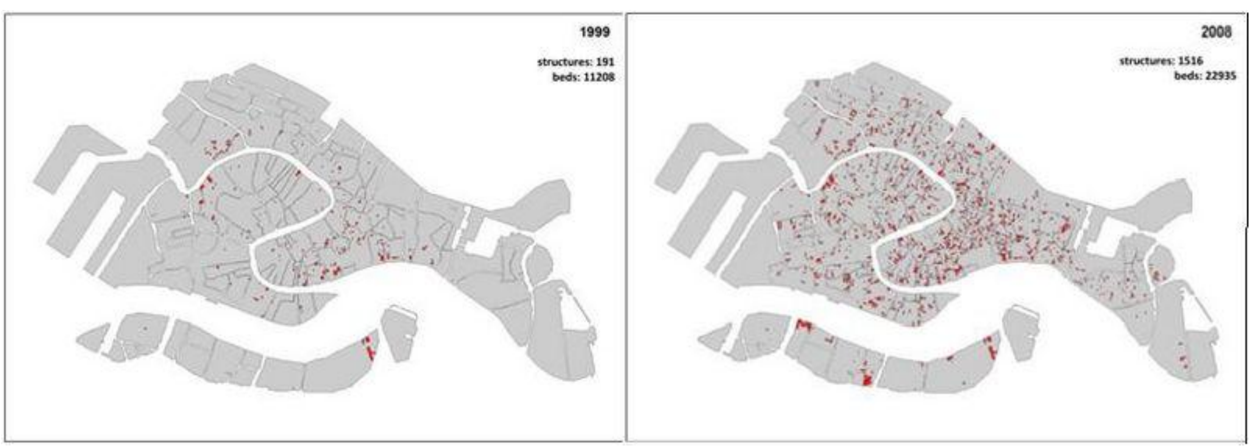


Figure 27: Hotel Proliferation 1999-2008

From the data compiled from the Statistics Office, it was determined that over four million bed-nights occurred in establishments owned by hotel businesses, and approximately 1.5 million

[24] Fabio Carrera. The Harbinger of Alberghi: Hotel Proliferation in Venice 2009.

occurred at non-hotel businesses, within the year of 2009. The measurement of bed-nights is a unit which describes both the number of people using the beds, multiplied by the length of their stay. It was also determined that approximately two million tourists arrived at these lodging establishments and stayed for an average of 2.73 days.

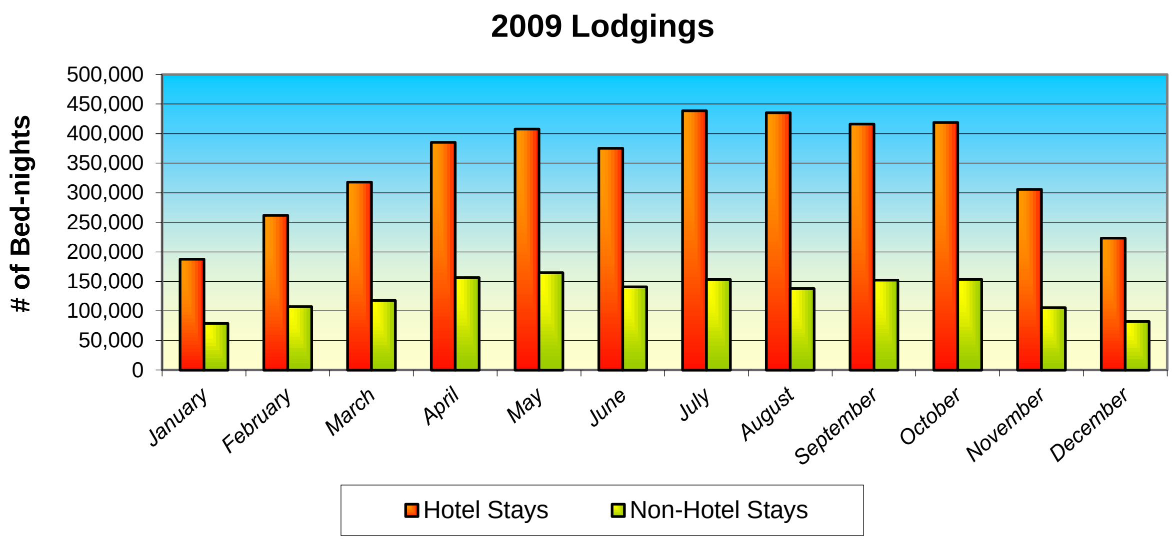


Figure 28: 2009 Lodgings by Month

The lodging data compiled over the months of 2009 is represented in the figure above. It demonstrates both the popularity of hotel businesses as the preferred method of accommodation for tourists staying overnight, as well as the popularity of the summer months for tourism within the city.

4.1.1.3 Tourist Attractions

The only tourist attraction data source that could be obtained this year was civic museum data. Figure 29 displays a table and a graph acquired from the 2010 Mobility Team. The attendance data per month for all civic museums in Venice is displayed. From the data, it appears that tourists visit the civic museums mostly in the months of April and October. Museums go through a period of inactivity from November to March.

1. I Musei Civici Veneziani

Tabella 1.1: I visitatori dei Musei Civici Veneziani

	2004	2003	2002	Var.%2004-2003	Var.%2003-2002
Gennaio	84.624	69.244	57.530	22,2%	20,4%
Febbraio	136.029	108.544	106.149	25,3%	2,3%
Marzo	152.484	145.523	146.274	4,8%	-0,5%
Aprile	213.026	199.820	171.616	6,6%	16,4%
Maggio		166.136	190.905		-12,9%
Giugno		149.465	151.824		-1,5%
Luglio		160.638	148.150		8,4%
Agosto		165.045	172.840		-4,5%
Settembre		163.624	167.382		-2,2%
Ottobre		181.909	169.440		7,4%
Novembre		107.151	105.935		1,1%
Dicembre		84.888	79.047		7,4%
Totale	586.163	1.702.007	1.667.092		2,0%

Grafico 1.1: I visitatori nei Musei Civici Veneziani

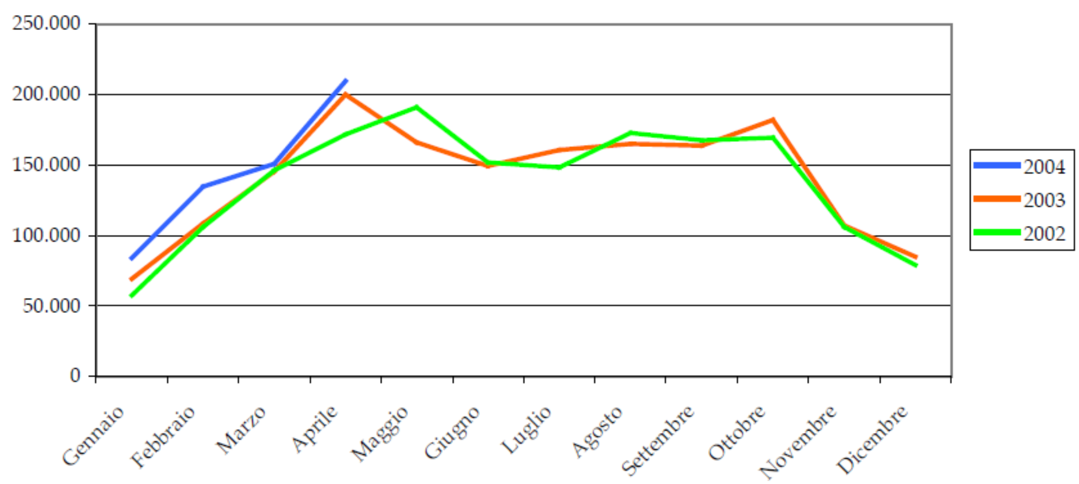


Figure 29: Civic Museum Attendance Data

Information on more specific civic museums was only obtained for *Palazzo Ducale,* which displays similar trends in attendance, as shown in Figure 30 below. The maximum number of tourists who attended civic museums in April 2004 was 213,026, and the maximum number of visitors who attended *Palazzo Ducale* in that same month was 149,097. This means that more tourists who visit Venice and attend one or more civic museums will go to *Palazzo Ducale.*

2.1 Palazzo Ducale

Tabella 2.1.1: I visitatori a Palazzo Ducale

	2004	2003	2002	Var.%2004-2003	Var.%2003-2002
Gennaio	59.614	44.410	40.926	34,2%	8,5%
Febbraio	91.347	75.598	76.010	20,8%	-0,5%
Marzo	108.535	104.948	107.535	3,4%	-2,4%
Aprile	149.097	139.543	122.444	6,8%	14,0%
Maggio		120.609	149.739		-19,5%
Giugno		111.911	119.838		-6,6%
Luglio		120.192	116.556		3,1%
Agosto		120.552	125.486		-3,9%
Settembre		117.512	124.476		-5,6%
Ottobre		127.896	124.297		2,9%
Novembre		74.536	76.210		-2,2%
Dicembre		58.899	51.727		13,9%
Totale	408.593	1.216.606	1.235.244		-1,5%
%su tot-MCV	*69,7%*	*71,5%*	*74,1%*		

Grafico 2.1.1: I visitatori a Palazzo Ducale

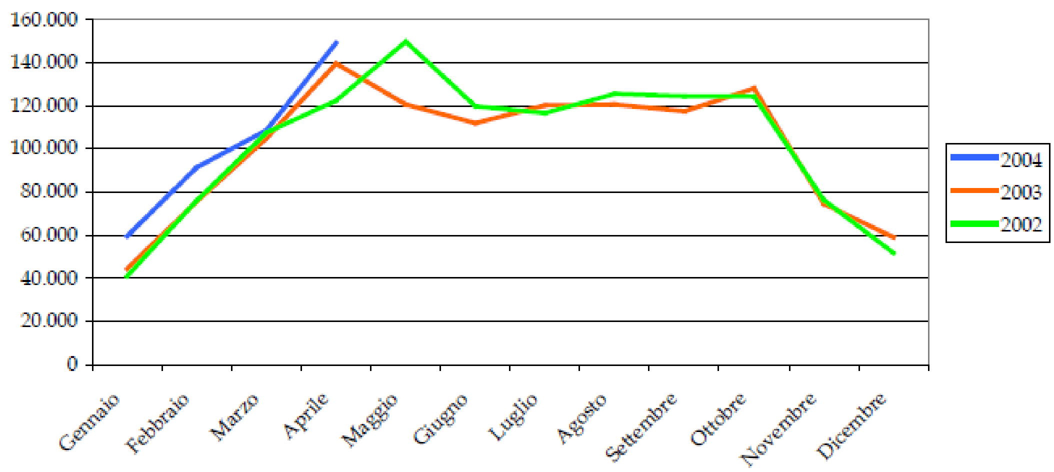


Figure 30: *Palazzo Ducale* Attendance Data

4.1.2 Waterbus Ridership

Actv is the local company which provides the area with mass transit services in the form of *vaporetti*. The company transports thousands of passengers around the city of Venice each day, including both tourists and Venetians. There were three Actv stops within the scope of the area of study for this project, which cover two of the many lines offered by the company, lines 1 and 2. Line 1 stops at approximately 20 stops and focuses upon the City Center by travelling around the Grand Canal. Furthermore, Line 2 is typically used as an express line, as it stops at many less locations between San Marco and *Piazzale Roma*. Along these lines, the three stops focused upon were *Sant'Angelo*, *San Samuele*, and *Santa Maria del Giglio*.

To observe the way that mass transit affects the district of San Marco, ridership data from the year of 2009 was acquired from the Statistics Office of the Commune of Venezia. From this the project team was able to determine the average usage of the Actv per day, as well as the typical number of people who both board and exit boats at the focus area each day.

The data for each of the stops under study was then placed into spreadsheets, and graphed for an analysis. The data was previously grouped into sections of the day, each consisting of a few hours, as seen in Table 8.

Table 8: Actv Hour Groups

Early Morning	7:00 – 9:00
Morning	9:00-11:00
Noon	11:00-13:00
Afternoon	13:00-17:00
Evening	17:00-19:00

To convert the data into a common form which could then be analyzed and studied for trends, all the raw passenger counts were converted into an hourly format, passengers per hour, and organized by their activity. The final line graph for the stops studied can be seen below.

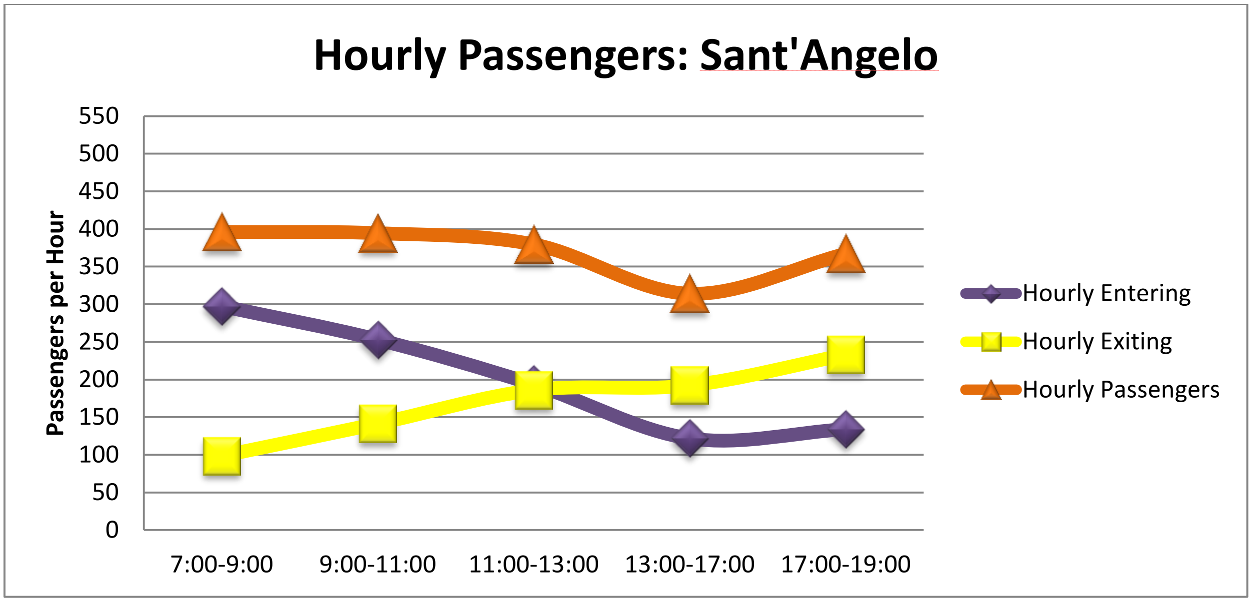


Figure 31: Passengers per Hour at Sant'Angelo Actv

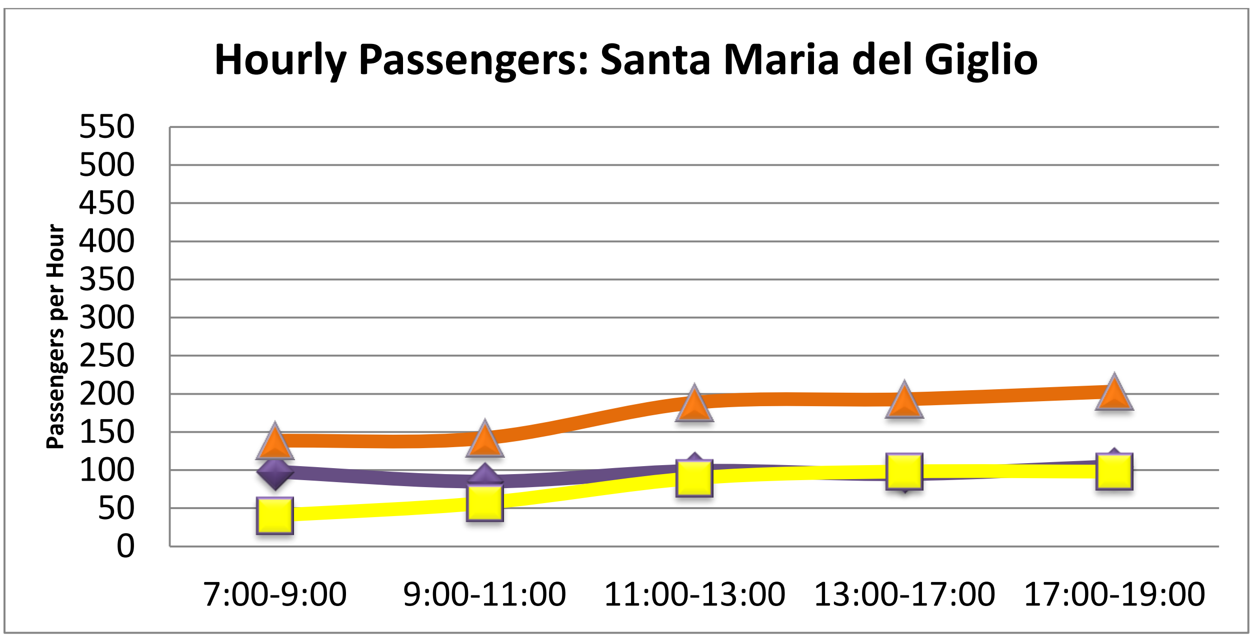


Figure 32 - Passengers per Hour at Giglio Actv

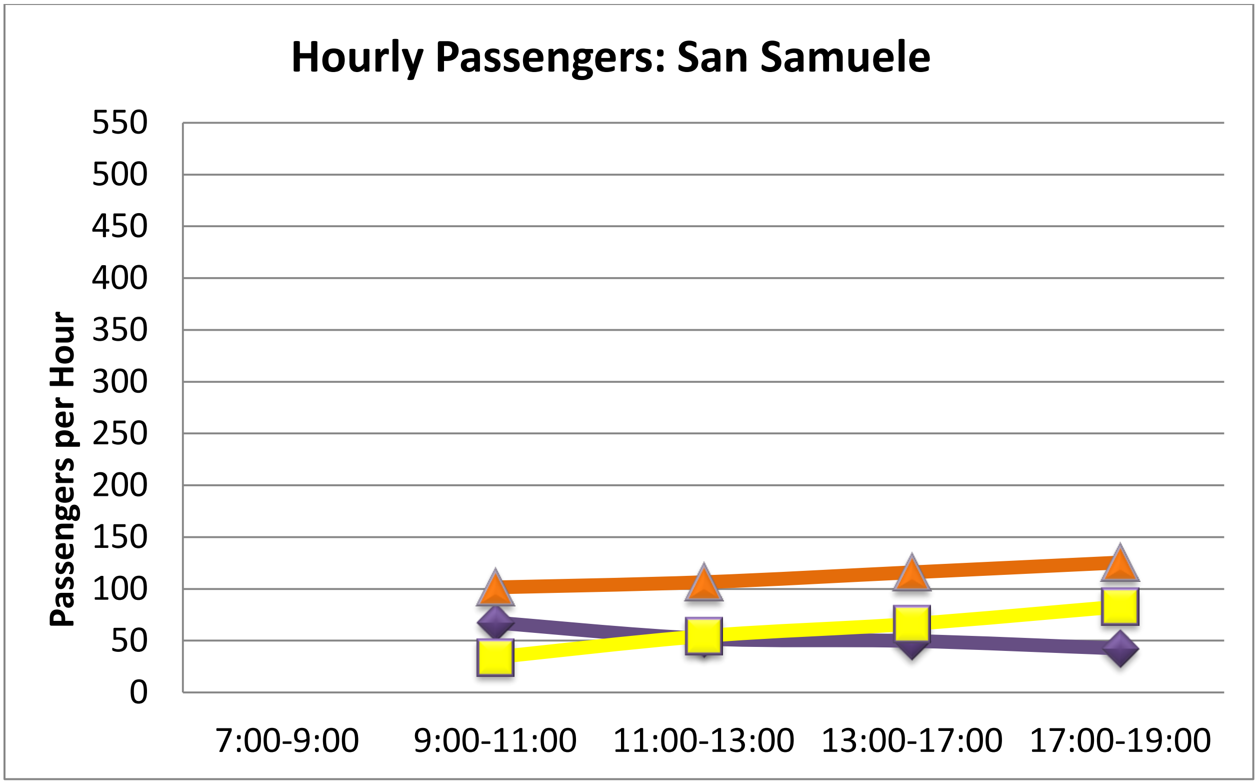


Figure 33 - Passengers per Hour at San Samuele Actv

One trend that is consistent between all of the stops studied was determined through statistical analysis. The team found that a significantly greater number of passengers arrive in the morning than depart at that time, and the opposite becomes true in the evening. Due to a large number of people commuting into the area in the morning, and leaving in the evening, it was determined that this would be partially due to tourists in the area, but also due to local Venetians who live outside the district of San Marco entering and exiting during their commuting times to and from work.

In addition, the number of passengers for each stop was compiled and compared for future analysis with other types of transportation. It is important to note that *Sant'Angelo* and *Santa Maria del Giglio* are stops on Line 1, which has been described as popular with both the local population, as well as with tourists, while the *San Samuele* stop is located on Line 2, an express line that helps tourists travel from points of entrance to large attractions.

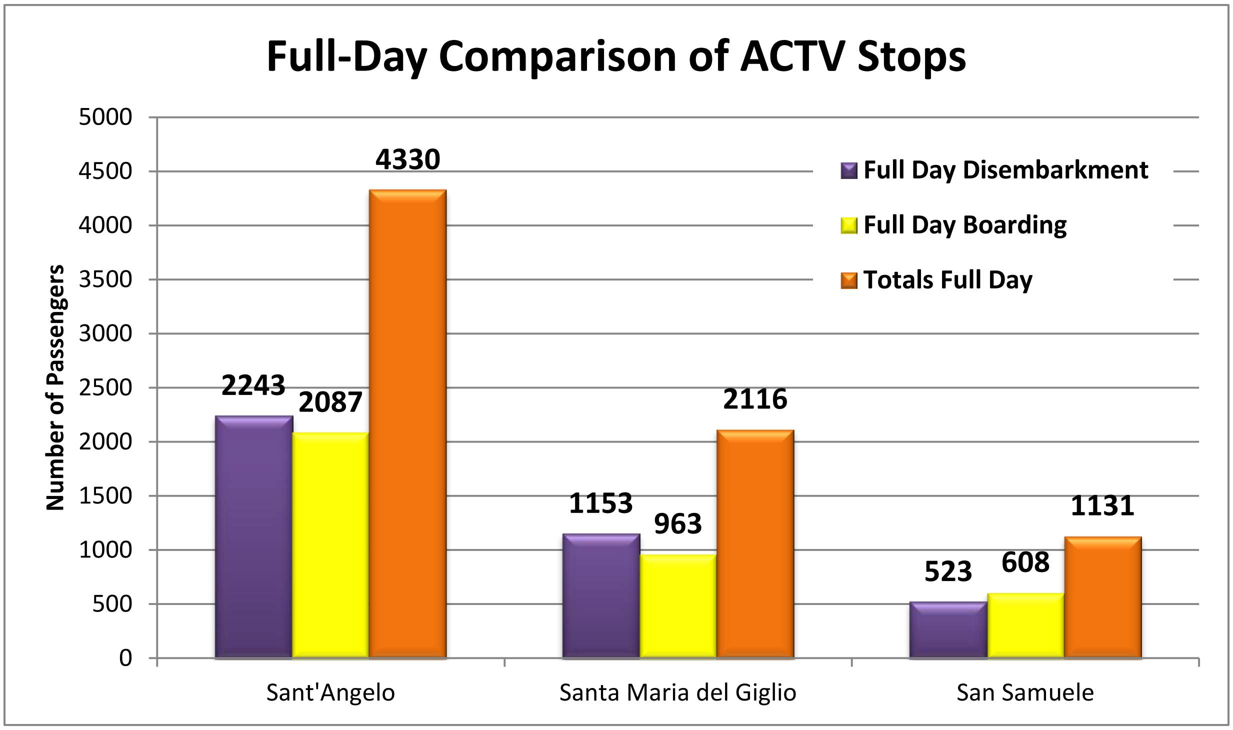


Figure 34: 2009 Actv Ridership

All of this information has helped describe the movements of pedestrians into and out of the District of San Marco; moreover, information in regards to the origins and destinations of the many tourists of the area will be required to model their behavior accurately.

4.2 Collected Data

As opposed to compiled data, the collected data was information that was physically gathered by the project team. The *traghetti* usage and bridge traversing trends are analyzed in the following sections.

4.2.1 *Traghetto* Crossings

While the intention was to count passengers at four *traghetti* stops in the San Marco district, the *Campo del Traghetto* to *Calle Lanza* crossing was out of operation during the project team's designated time in Venice. Therefore, counts were performed at the other three *traghetti* crossings in the district and results are given for each *traghetto's* full hours of operation collected over several days.

The following map displays the comparison of passenger usage at each *traghetto* stop and the proportion of passengers entering versus the proportion of passengers leaving the San Marco district.

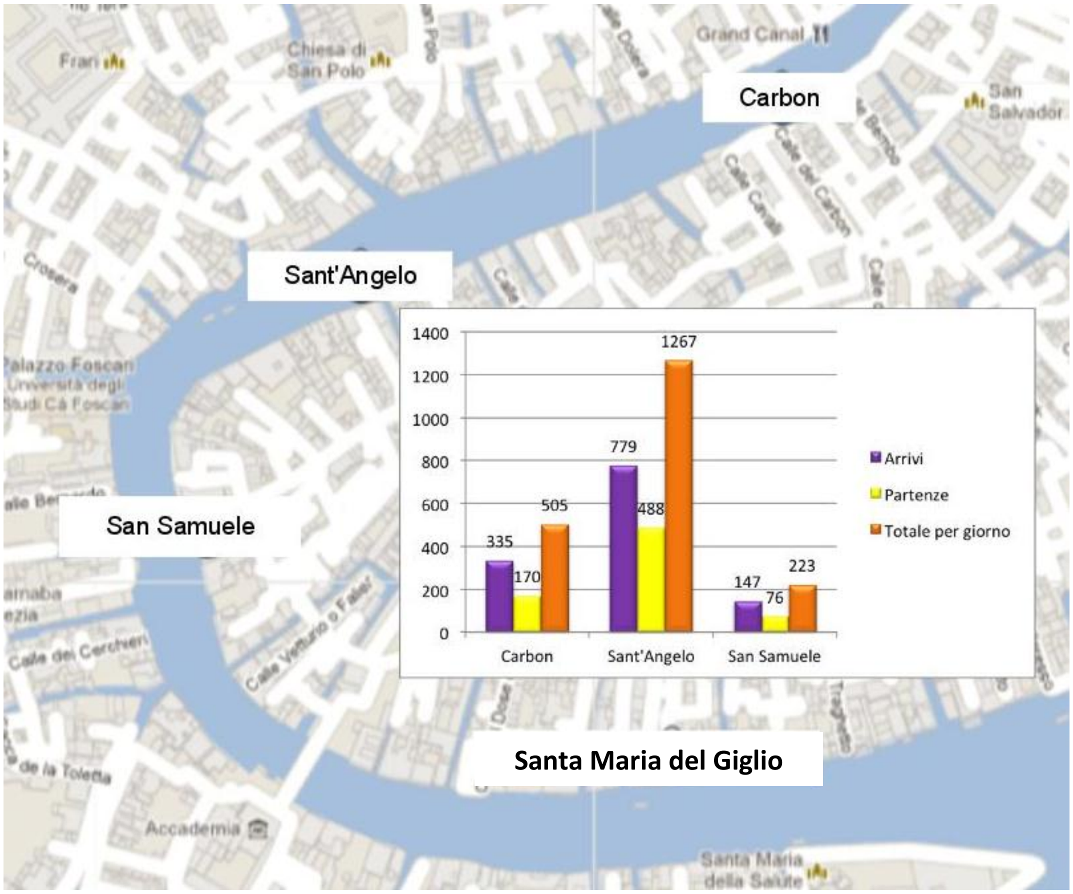


Figure 35: *Traghetti* Passengers Entering and Leaving the Study Area

The orange bars on the graph represent the total number of passengers that used each *traghetto* stop in that day, illustrating that *Sant'Angelo* was more frequently used than the others. However, it also operates for more hours throughout the day.

For all of the *traghetti* stops, the magnitude of passengers entering San Marco was greater than the magnitude exiting San Marco. This is because the *traghetti* operate mostly during the morning hours, so locals using the *traghetti* to get to get to work used other means of transportation to return home, if they were traveling when the *traghetti* were no longer operating. Another reason residents may not have been using the *traghetti* to return home is because they were not necessarily in a rush to go home, as they were on the way to work, so they could take less direct means.

The following gradient map shows the work locations in San Marco. All of the residents who were coming from outside of the region must cross the Grand Canal, and an inexpensive and quick way of doing so was the *traghetti*.

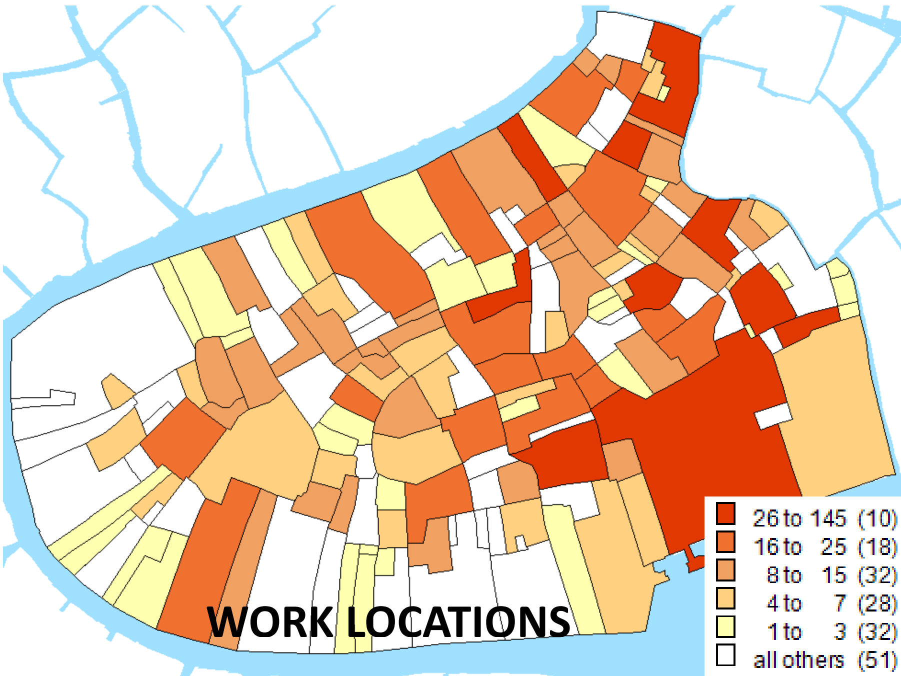


Figure 36: Gradient Map of Work Locations

The usage of *traghetti* usage was less than expected, considering most locals would more than likely not want to use the major bridges that tourists frequently cross.

4.2.2 Bridge Usage

After conducting preliminary counts to determine specific trends in traffic flow it was determined that, of the seven bridges in the project focus area, only three of them carried a significant magnitude of traffic flow. The project team focused their results and analysis on those three bridges—*Ponte del la Cortesia*, *Ponte San Moisè*, and *Ponte dell'Accademia* (see Figure 38).

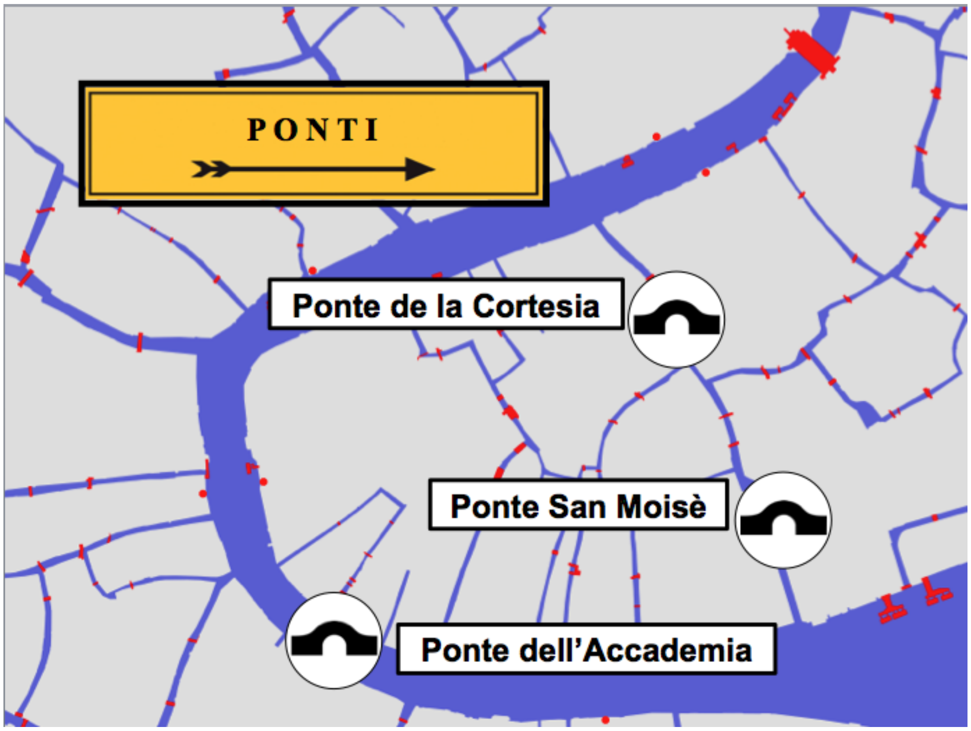


Figure 37: Bridges studied in Study Area

Figure 39 depicts the flow of traffic entering the San Marco district using *Ponte de la Cortesia*. Over time, the amount of pedestrians that cross the bridge gradually increases, with a slight peak in the middle of the day.

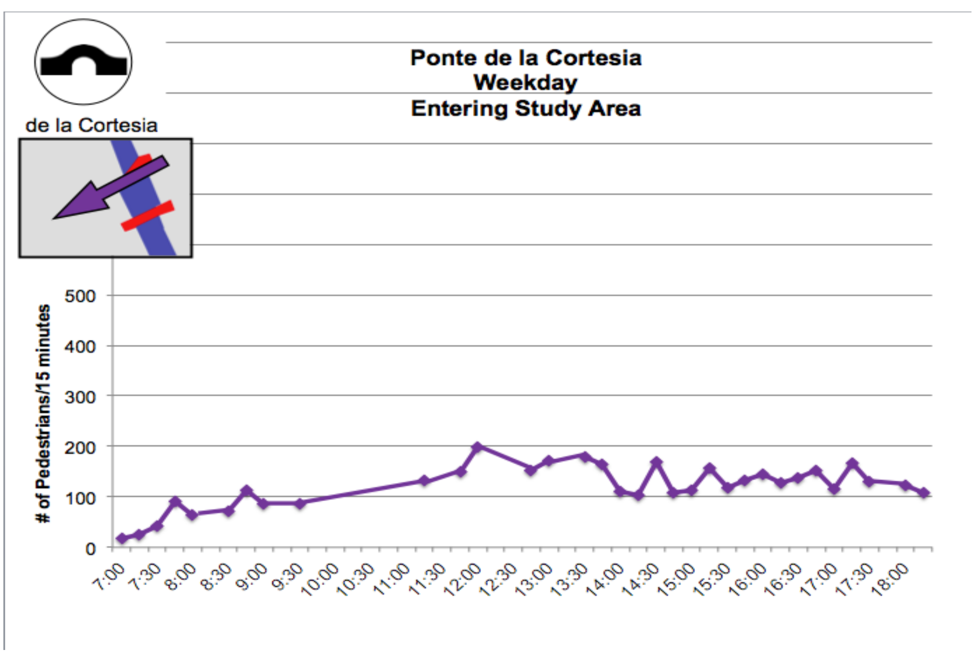


Figure 38: Traffic Across *Ponte de la Cortesia* Entering the Study Area

Figure 40 represents the flow of traffic exiting the district. This graph illustrates a similar trend, with an increasing usage as the day passes. However, the level peaks a little later, between 13:00 and 15:00.

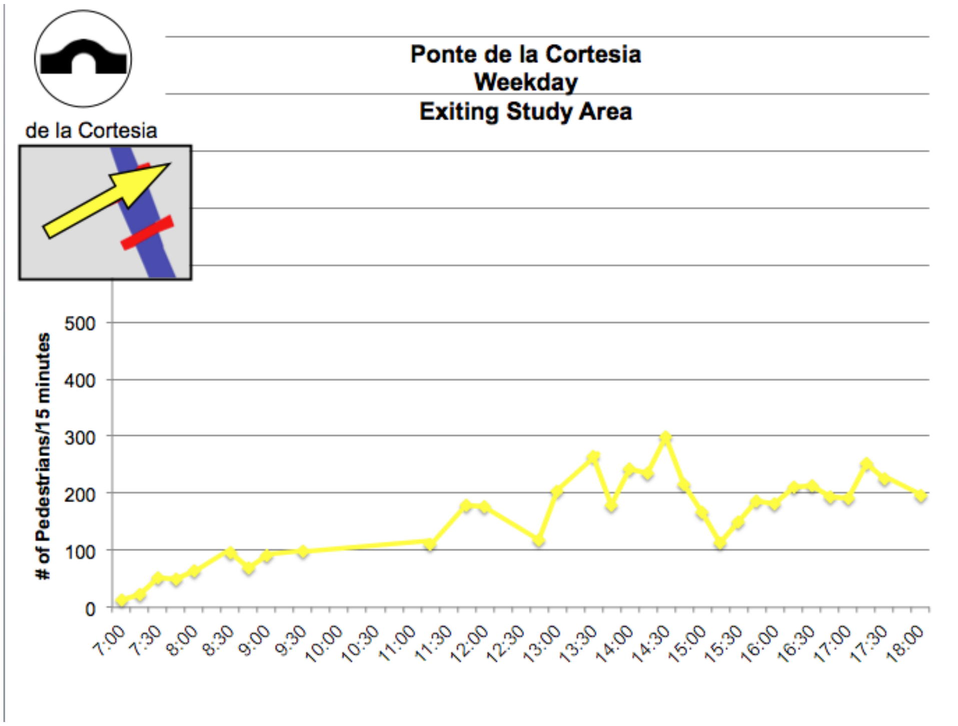


Figure 39: Traffic Across *Ponte de la Cortesia* Leaving the Study Area

Together, the overall usage of *Ponte de la Cortesia* increases significantly from the morning to the evening and tapers off towards the end of the data collection period (as seen in Figure 41). This is likely due to the location of this bridge. It is located near a busy shopping and business sector of the San Marco district and can be used to travel to *Palazzo Fortuny*, a popular museum for visitors.

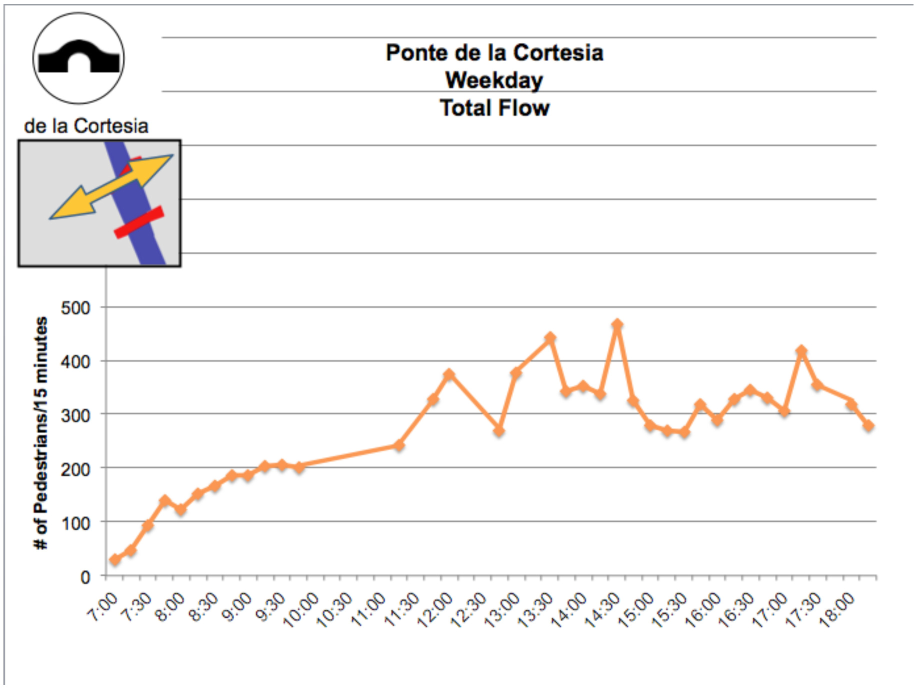


Figure 40: Traffic Into and Out Of the Study Area via *Ponte de la Cortesia*

The trend of pedestrians entering *Ponte San Moisè* experiences a more significant peak, as illustrated in Figure 42, than that of *Ponte de la Cortesia*. *Ponte San Moisè* peaks at 14:45 by a magnitude of over 500 pedestrians, and immediately begins to decrease.

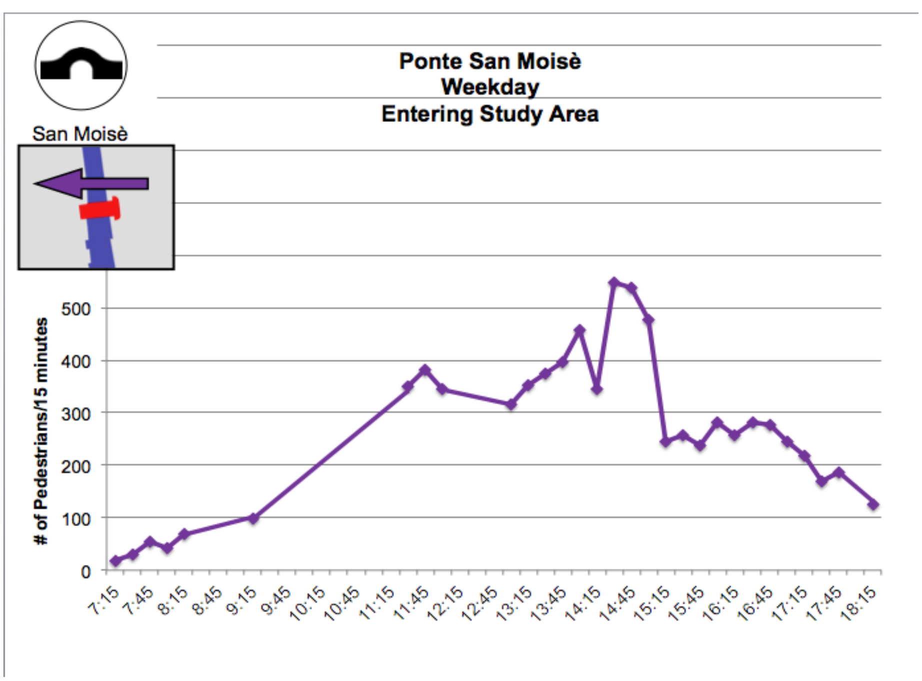


Figure 41: Traffic Across *Ponte San Moisè* Into Study Area

The succeeding graph demonstrates the flow exiting the study area for *Ponte San Moisè*. The increase in flow occurs much earlier in the morning and remains at a fairly consistent maximum of approximately 300 to 350 pedestrians and then decreases in the late afternoon.

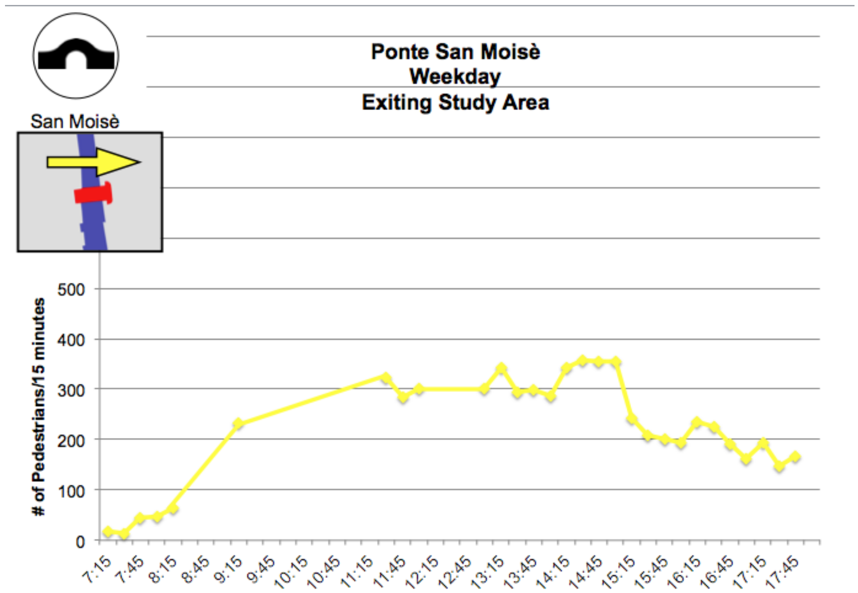


Figure 42: Traffic Across *Ponte San Moisè* Exiting Study Area

The total flow crossing *Ponte San Moisè* is much larger, as seen in Figure 44 below. The peak total flow is about 900 pedestrians and occurs around 14:30. The peak is most likely this high because this bridge is located between St. Mark's Square and the Accademia Gallery and Bridge, popular tourist destinations.

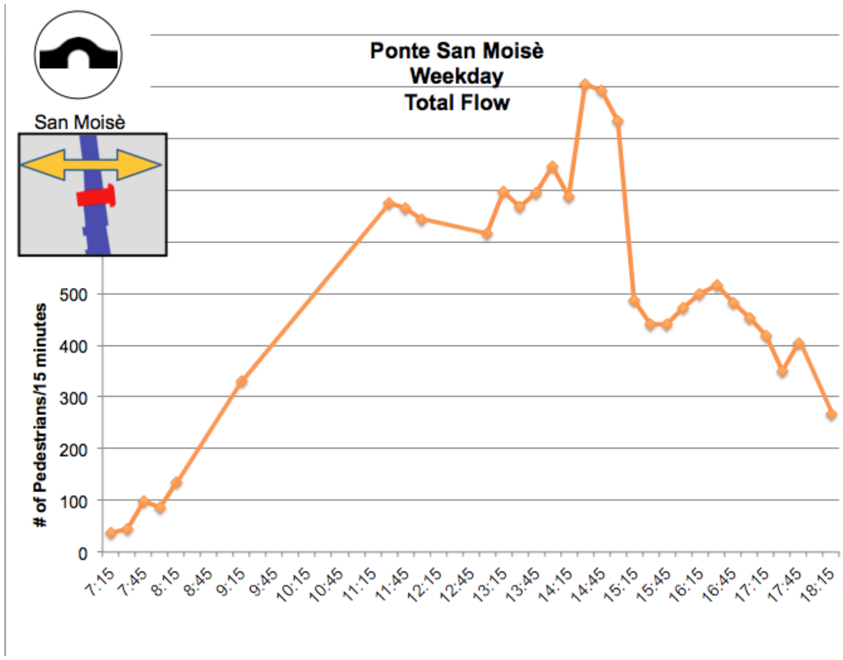


Figure 43: Traffic Into and Out Of Study Area via *Ponte San Moisè*

The next series of figures are representative of *Ponte dell'Accademia*. Figure 45 shows the flow of pedestrians into the San Marco district. After reviewing data collected by the 2010 project team, it was assessed that data need only to be collected during the hours that were previously determined to be the pedestrian commute times, in the early morning and early evening. The trend is almost linear, and there is hardly a distinguishable peak. However, flow does achieve its maximum at approximately 17:00.

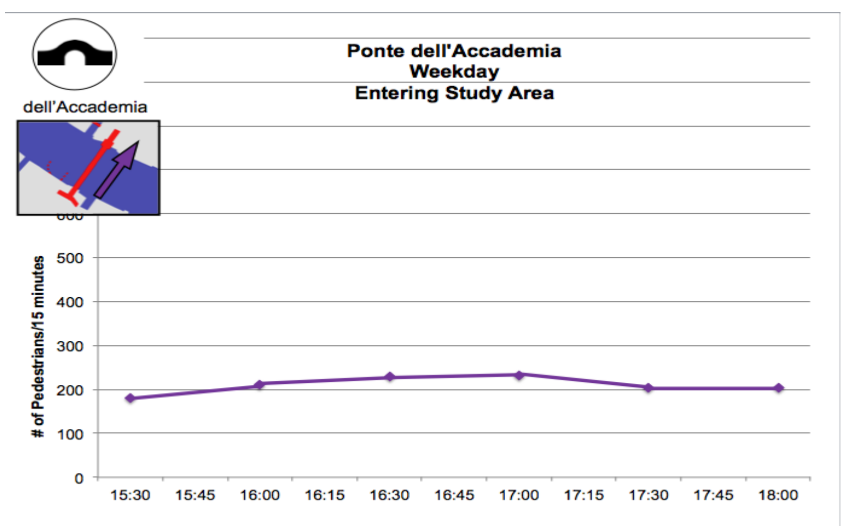


Figure 44: Traffic Across *Ponte dell'Accademia* Entering Study Area

The flow out of the San Marco district is fairly linear as well, but a peak does occur around 16:00. This occurrence is logical, because the peak traffic volume for *Ponte San Moisè* entering the study area is around 15:00, so the pedestrians travelling from that direction to exit the San Marco district would reach *Ponte dell'Accademia* at a later time.

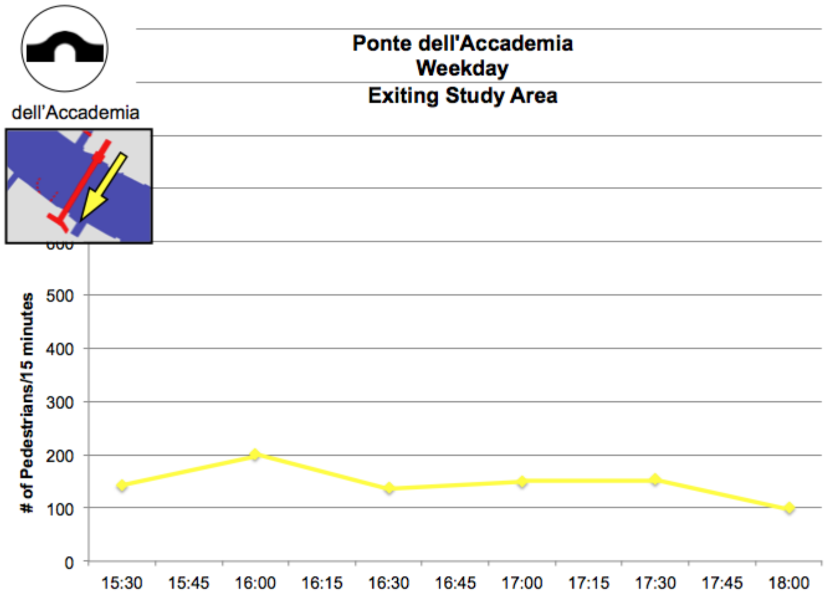


Figure 45: Traffic Over *Ponte dell'Accademia* Exiting Study Area

The following graph, in Figure 47, contains the total flow of traffic in the early morning and early evening. Each time bracket contains its own maximum volume peak. Surprisingly, *Ponte dell'Accademia* was not more heavily used by pedestrians in comparison to other focus bridges. Despite it being the only other bridge, aside from the Rialto Bridge, that crosses the Grand Canal, there is more pedestrian traffic flow across alternate bridges.

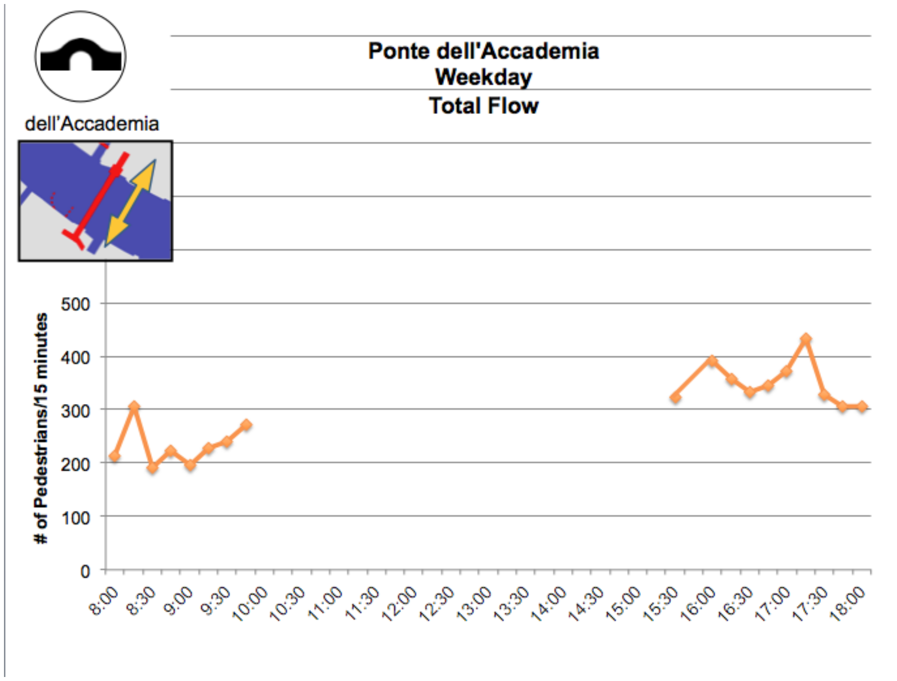


Figure 46: Traffic Flow Into and Out Of Study Area via *Ponte dell'Accademia*

As seen in Figure 48, *Ponte San Moisè* has the highest flow on average weekday of the three bridges, while *Ponte de la Cortesia* and *Ponte dell'Accademia* have a significantly lower flow.

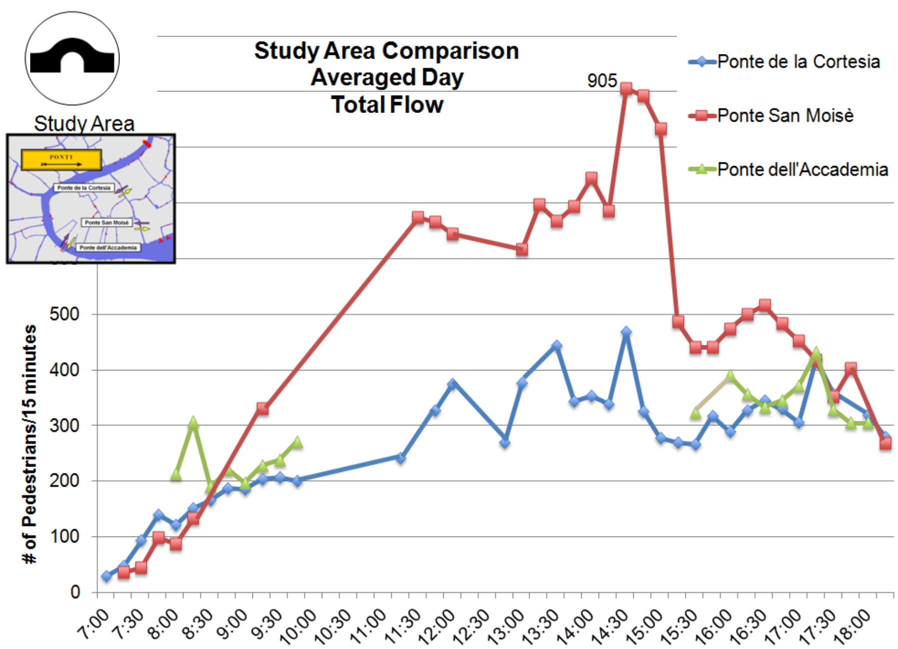


Figure 47: Total Pedestrian Flow Over the Study Area Bridges

As time progressed throughout the day, more and more pedestrians crossed the bridges in their travels to work, school, or tourist destinations. The amount of walkers crossing the bridge eventually reached an apex in the afternoon or evening, and decreased for the rest of the night. This is repeated daily, and there was a similar trend on weekends.

4.2.2.1 Pedestrian Typology

In addition to collecting data for the direction of flow across the three focus bridges, tourists were also isolated and quantified from the masses to model the different walking paths between tourists and Venetians.

Figure 49 portrays the tourist and Venetian flows at *Ponte de la Cortesia.* At both time brackets studied, the number of Venetian crossings was greater than the number of tourists, drawing the conclusion that *Ponte de la Cortesia* is located near more residential and business locations than tourist attractors.

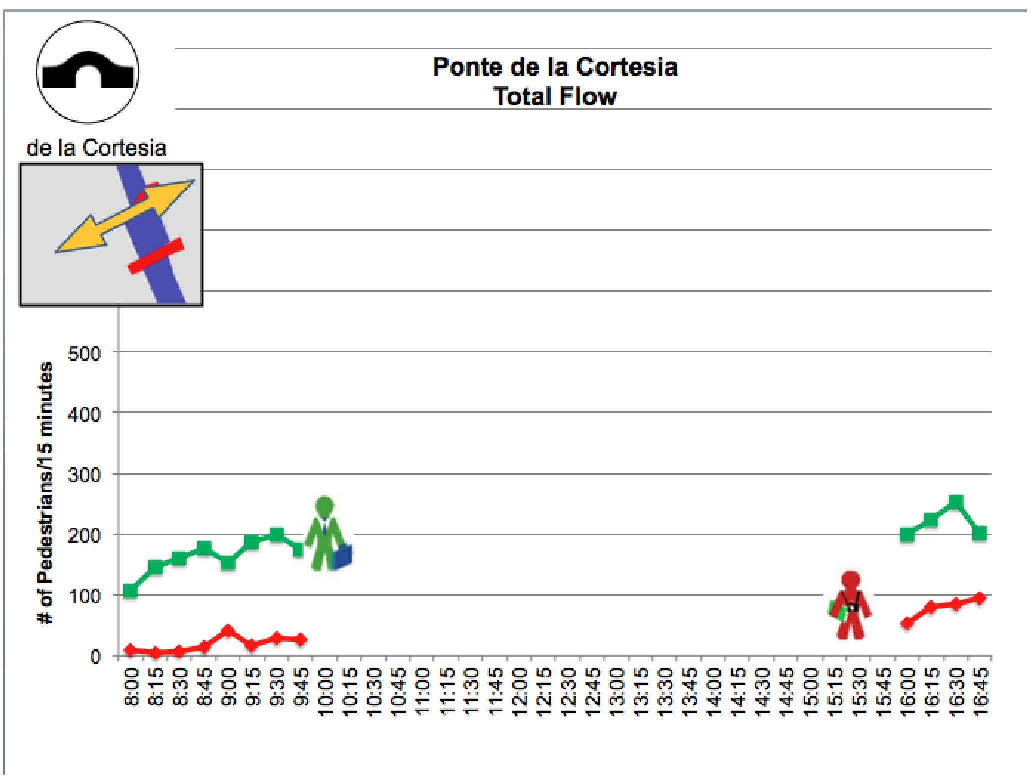


Figure 48: Flow Comparison of Venetians and Tourists Into and Out Of Study Area Across *Ponte de la Cortesia*

At *Ponte San Moisè*, data was also collected in the morning and early evening hours. The tourist and Venetians trends switched during the day, as seen in Figure 50. Where locals were dominant in the morning hours, tourists dominated the evening hours. Locals must be using the bridge in the morning to commute to work, but, knowing that tourists populate the area later in the day, use another means of commuting home.

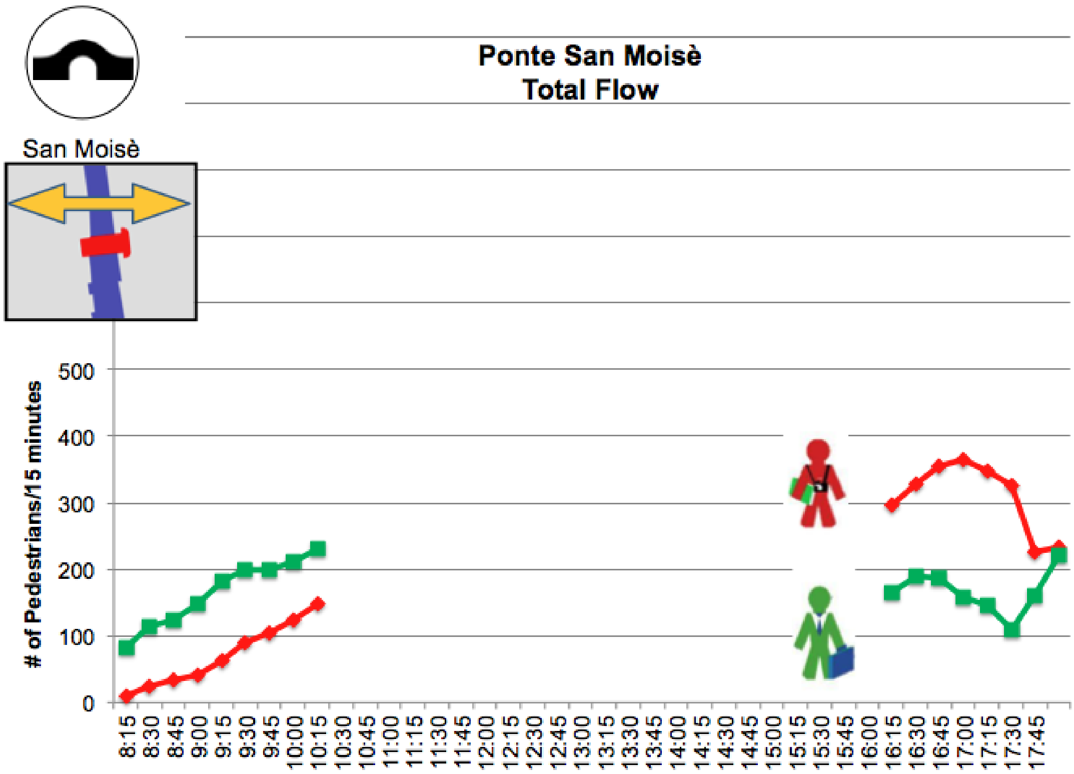


Figure 49: Flow Into and Out Of the Study Area Across *Ponte San Moisè*

Ponte dell'Accademia receives more locals than tourists in the morning and evening hours. Typically, *Ponte dell'Accademia* is considered one of the three major tourist attraction in Venice that make up the "Tourist Triangle". There is the possibility that tourists cross *Ponte dell'Accademia* more in the afternoon to enter the San Marco district and visit the attractions in the area.

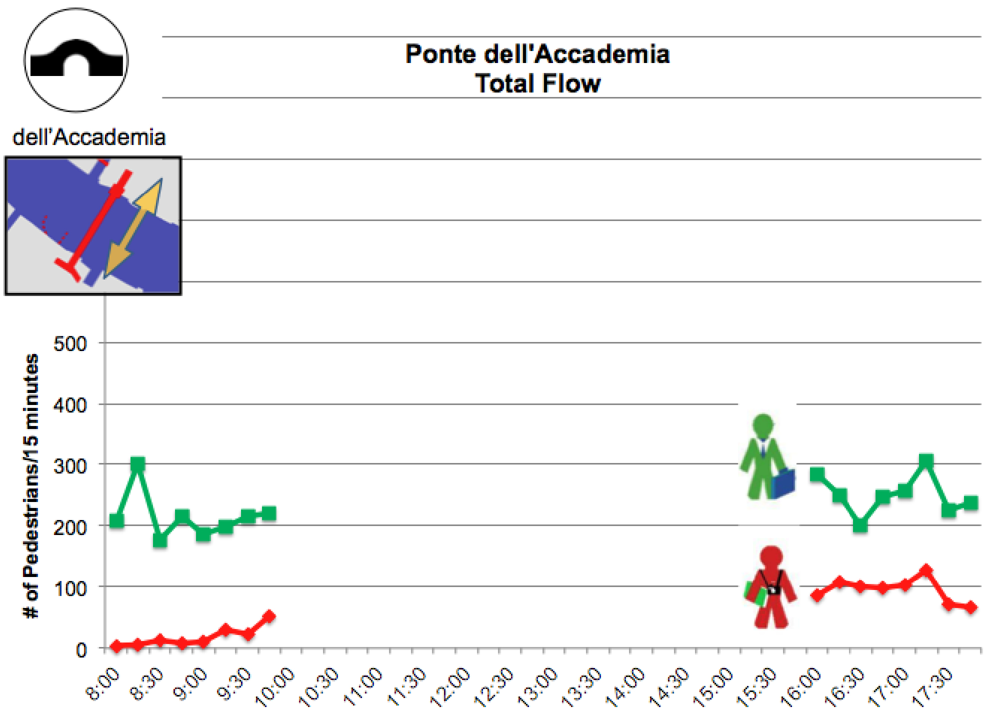


Figure 50: Flow of Venetians and Tourists Into and Out Of the Study Area Across *Ponte dell'Accademia*

A comparison of all three focus area bridges, as seen in Figure 52, shows that Venetians were the major contributors to the crossing traffic flow. Of the three ways to cross the Grand Canal, *gondola* crossings, waterbuses, and bridges, bridges are the most direct and only option without charge. More Venetians use these three bridges in the morning because of these reasons, and because tourists may not be out at those hours.

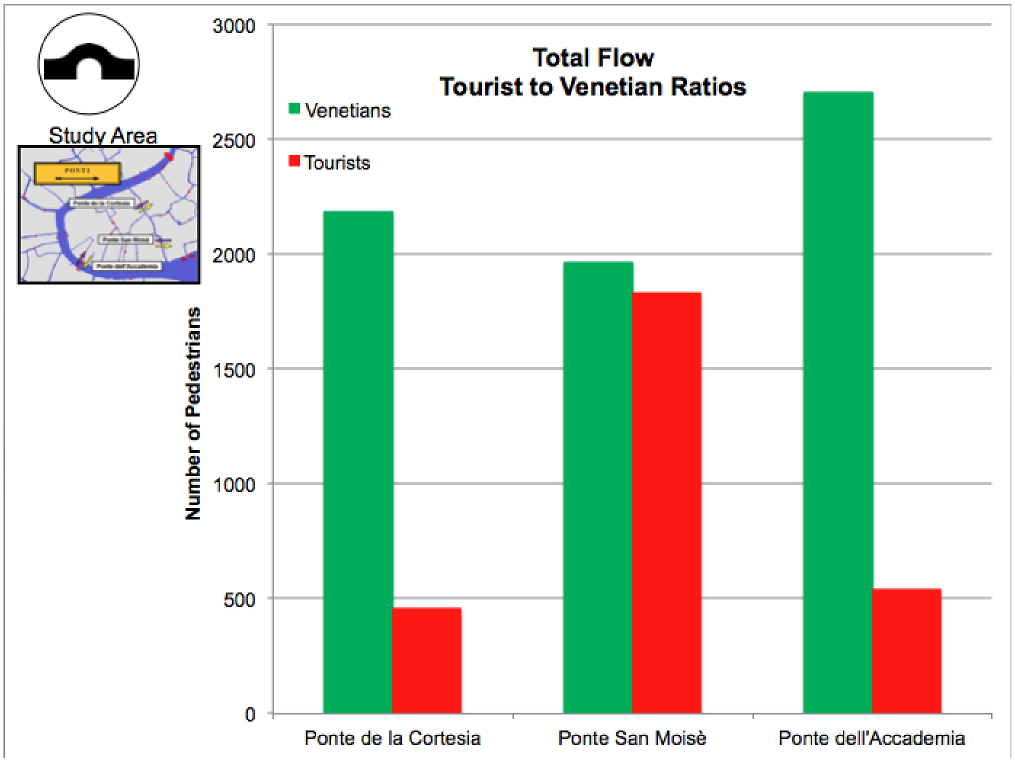


Figure 51: Total Tourist and Venetian Flow Into and Out of the Study Area Over Bridges

4.3 Study Area Synopsis

Once the data was compiled for the Actv stops and collected for the *tragetti* stops and bridges within the study area, the datasets were analyzed. Figure 53 demonstrates the total flow for an average day at each of the entrances and exits for which the team gathered data within the study area.

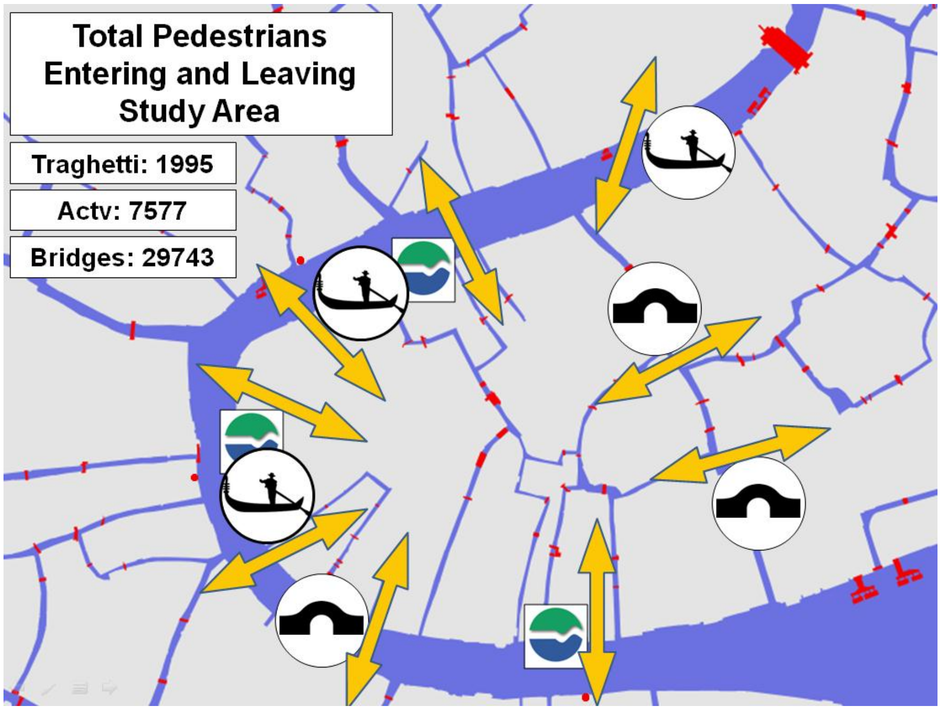


Figure 52: Total Number of Pedestrians Entering and Exiting the Study Area on an Average Weekday

When the number of passengers utilizing the Actv and the *traghetti* were compared, it was evident that the Actv carried almost four times as many passengers. The number of pedestrians using bridges clearly outnumbered the boat transportation because of the higher quantity of bridges compared to the boat stops, the ease of access, and the lack of a utilization fee.

There was also a consistency in the number of people entering and exiting the study area throughout the Actv, bridge, and *traghetti* data. For each type of data, there was a greater number of people entering western San Marco than leaving. This was because of the Venetians traveling to work or school in the district, and the high number of tourists traveling between the *Piazza San Marco* and *Ponte dell'Accademia*.

4.4 Video Surveillance Study

The collection of a number of video feeds at specific choke points enabled the team to make several comparisons to determine the feasibility of using remote counting techniques with video feeds. The comparison between different camera orientations and angles demonstrated the possibility of leveraging existing video camera networks to collect pedestrian traffic data.

4.4.1 Camera Orientation Comparison

The remote video counts of each camera set up scenario were statistically similar to the conducted field counts. The compared counts at each location all had alpha values under .05. Table 9 shows the precision of the counts at each orientation and during high and low flow scenarios.

Table 9: Statistical Comparison of Camera Orientations

Camera Orientation	Low Flow Comparison (% Similarity)	High Flow Comparison (% Similarity)
Bird's Eye	100	97.7
Horizontal Perpendicular	100	98.06
Horizontal Straight-On	96.08	95.99

Though the horizontal perpendicular orientation was the most statistically similar, it was determined qualitatively that the Bird's Eye view orientation provided the best scenario for conducting remote video counts. This was concluded from counter preference. These counts were also conducted in the least amount of time. However, all the orientations can provide adequate video feeds for collecting traffic data.

Video feeds were also collected at night, but the limited exposure on the cameras coupled with the lack of ambient light made remote video counts in these scenarios impossible.

4.4.2 Counting Technique Comparison

There was no statistical difference between each team member's counts in both high flow and flow scenarios. There was also no statistical difference (alpha value <.05) between the video manual counts and the manual field counts in any of the tested flow or camera placement scenarios. This presents the conclusion that counting remotely through video feeds is feasible and will provide accurate pedestrian traffic flow data.

4.5 Model Feasibility

The autonomous agent model is a resource for higher understanding of pedestrian mobility in Venice. This model was coded in HTML5 language for reasons of its flexibility as a language, as well as its ability to be easily reached by the public through almost any current internet browser. This language allowed for the necessary logic to be developed and implemented into the model via a collaborative effort between the project team and Santa Fe Complex.

4.5.1 Environmental Framework

The first step in ensuring the model's accuracy was to create a virtual environment for the agents to exist and occupy. The design utilized maps created through geospatial information systems, known as GIS. The GIS mappings constructed the virtual environment of the model by using accurate archived data collected throughout the years of studies done within the City of Venice. The most important aspect of this environment was the accuracy of the locations of pathways within the city. Both a satellite image as well as the pedestrian path layer of the project team's GIS map can be seen below.

Figure 53: Comparison Between Satellite and GIS Maps

The conglomeration of these pathways, as stated previously, are made up of edges, which are constructed as a series of nodes, the building block of geospatial information. Each of these nodes has an identification number to be referenced and knows its distance from other nodes within the network. This setup is known as flood-fill networking. The GIS layer containing the pedestrian walkway information contains enough detail to properly map all bridges, thruways, and dead ends within Venice; furthermore, its contents are updated every few years, making it both a versatile and continuously accurate modeling environment.

4.5.2 Agent Movement

The second main component of the model's function was contingent upon the behaviors of the agents within it. These agents served the purpose of providing a visual representation of the various types of their pedestrian counterparts which move about the city on a daily basis. Each of these agent types behaved differently within the model and travel to different locations at different times based on their decisions made throughout the day. These trip planning decisions have many factors involved, and were made autonomously, based upon the 'rules of attraction' described in Section

3.3.2, as well as decisions made on-the-fly as they cross particular nodes. In addition, to improve functionality, the notion of chronological behavior was also implemented to aid in this decision making process and augments these rules of attraction based upon the current time within the model.

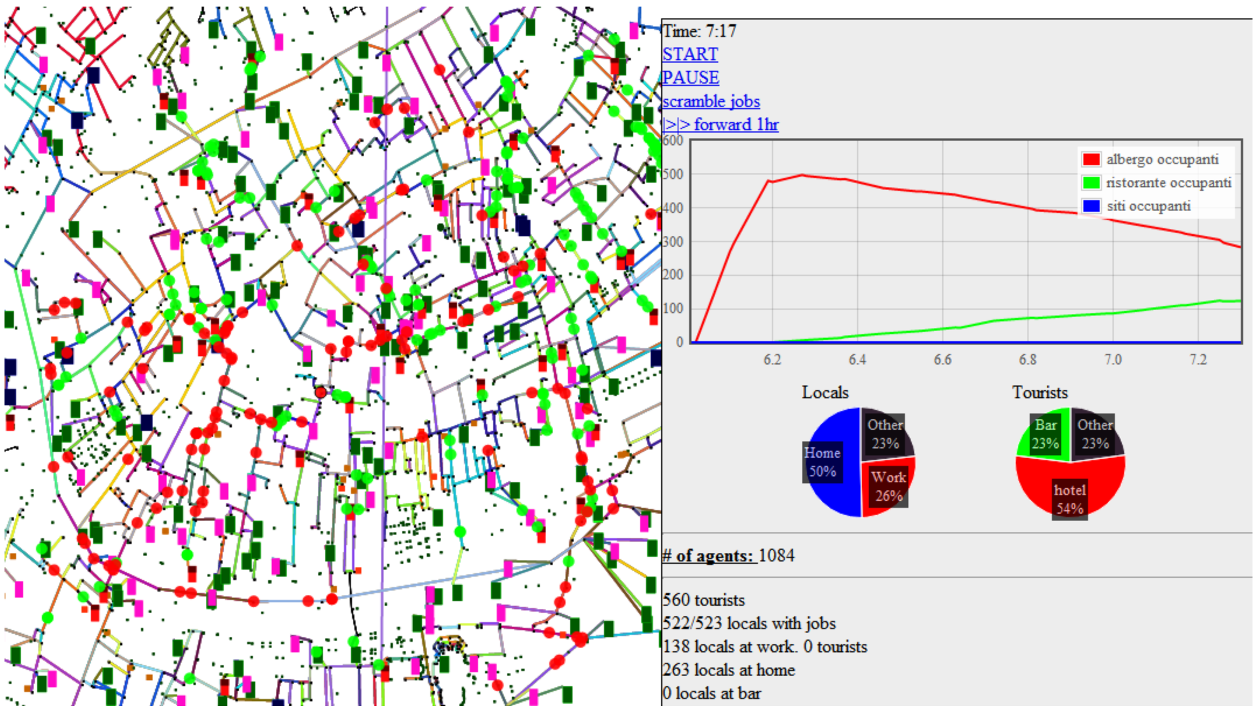


Figure 54: Morning Commuting in the Model

The behaviors of different pedestrian agent types were modeled through their individual probabilities of being in attendance at one of many types of locations. Certain trends were taken into account, such as the commuting of the local population from their residence to the work in the morning, while tourists are simultaneously either getting breakfast at a food establishment, or not out and occupying the streets just yet. In the figure above, the two types of agents, locals and tourists, are represented by green and red dots on the map, respectively. On the right side of the screen, a time based plot, as well as pie charts containing the current locations of all pedestrians, can be found for more quantitative information regarding the conditions present in the model. As the day progresses, the crowds move to time-appropriate locations. Below, another image taken at approximately noon in the model shows most agents have ventured to food establishments for lunch.

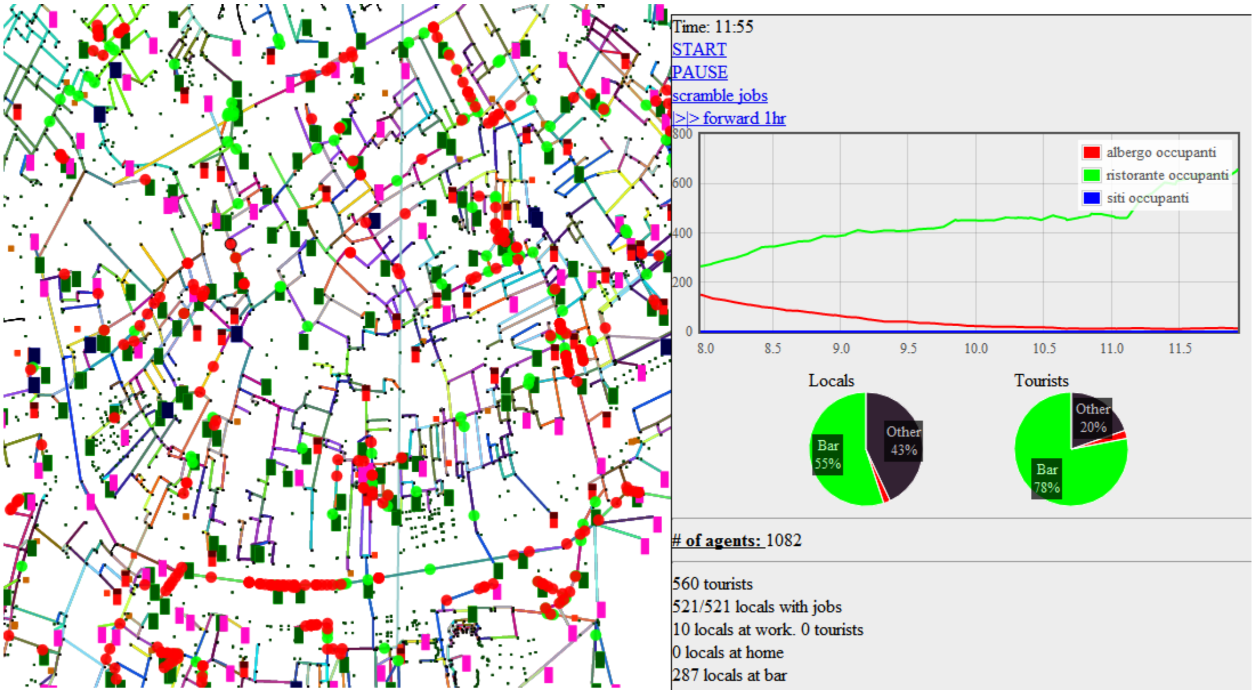


Figure 55: Lunchtime for Agents

4.5.3 Final Model Functionality

The autonomous computer model provides many functions that allow for a better understanding of the movement of pedestrians within the city of Venice. First and foremost, the model brings together data from a wide variety of sources, organizes it into one single location, and presents it in a visually appealing and user-friendly manner. By compiling this data in one spot and using algorithms to determine behaviors, the model allows for any gaps in data to be accounted for. Once this has been established, the model serves two main purposes, based upon the time of reference.

Firstly, the model serves the purpose of providing an accurate visualization of the dynamic movement of those within the city right now; serving the important purpose of filling in the gaps of data that would be otherwise missing. Secondly, the data involved in the processing of this model can be extrapolated for predictions of how movement in the city will behave in the future. By assessing data, and making these predictions available to the city, proper preventive measures can be taken to alleviate some of traffic's stress upon the city's infrastructure and the people within it.

5 Recommendations

To further the development of a comprehensive pedestrian computer model, the 2011 project team made several suggestions. These suggestions include continuing data collection and compilation for the entirety of Venice and improving collection techniques.

5.1 Pedestrian Mobility Evaluation Recommendations

More pedestrian counts can be performed to improve upon the computer model and gain a more comprehensive understanding of pedestrian mobility in Venice. A continuation of the studies of the San Marco district as well as the other five districts of the city will supplement the data collected this year and in previous years for the ultimate goal of creating a model that will be used to prevent traffic congestion.

5.1.1 Continued Raw Data Collection

Additional raw data should be collected and compiled to supplement the counts. Each census report and more Actv data should be archived in the same public location as the data collected this year. More data concerning hotel occupancy and museum attendance should also be compiled.

5.1.2 Expansions of Bridge Data Collection

The more data that is collected at bridges, the greater the program's ability to accurately model traffic flow. Therefore, further counting should be performed at the three bridges utilized this year. Additionally, counts should be conducted at the other bridges in the San Marco district and throughout Venice.

Data should also be collected at more times during the day. This year's team chose to collect at peak volume times. Since WPI projects are restricted to the beginning seven weeks of the tourist off-season in Venice, collecting more data and at other times of the day would provide a more accurate extrapolation for traffic during the peak tourist months. To provide the model with more data, other times should be considered.

Continued studies into the proportions of Venetians and tourists that utilize specific bridges will help provide insight into the bridge choices each agent type is likely to use when there are more than one option.

More detailed agent distinction would provide more accurate behavioral patterns for the model. Distinguishing between day tourists and overnight tourists would be very beneficial, as each type has a different origin and would behave differently throughout the day. Day tourists typically visit only the major attractions, due to the individual's time limitations. Overnight tourists visit secondary attractions and spend more time at each site.

5.1.3 Intersection of *Traghetti* and Pedestrian Traffic

Further studies of the *traghetti* stops analyzed by this project should be conducted. The rest of the *traghetti* stops along the Grand Canal should also be studied to better thread together the connection between *traghetti* transportation and pedestrians on foot. Other useful information that should be collected is the percentages of locals and tourists who use the *traghetti*. A thorough analysis into whether or not *traghetti* are a critical mode of transportation for pedestrians would be of use to the sponsors of this project at the City of Venice Department of Mobility and Transportation.

5.1.4 Study of Other Situations

This year's project team decided to count during ideal circumstances, without unusual weather conditions such as heavy rain, extreme cold, thick fog, or during *aqua alta*, high tides. These types of weather conditions impair traffic mobility and should be studied in order to gain a complete representation of Venetian mobility in the model.

Other mobility impairments that data should be collected for would be pedestrians with handicaps, strollers, and carts. These features slow down an individual's pace and consequently impair mobility. Age brackets should also be accounted for, because elderly people are more likely to have a slower pace than those in younger age brackets.

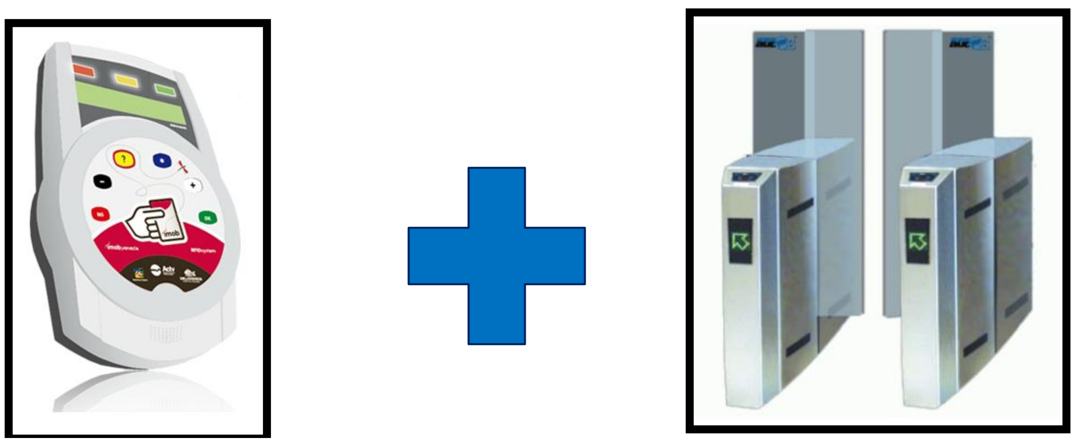
5.1.5 Video Surveillance Counting Techniques

Further fieldwork should be conducted with respect to video surveillance. More video clips recorded of more traffic situations should be counted. Traffic situations to count would be during heavy or light rainfall, dense or light fog, or festivals. Attempts should be made to obtain surveillance footage from the *vigili urbani* and the *polizi locali* to better determine the feasibility of counting from surveillance technology currently implemented in the city.

More extensive research in recognition software should be carried out. Employing an autonomous agent-based computer model to eliminate the reliance on man-hours is the ultimate end goal of this project, and efficient software to complement the computer model would achieve that goal.

5.2 Imob and Turnstile Partnership

The Actv public transit system employs Imob scanners to validate the tickets of every passenger who boards the *vaporetti*. Every time a ticket is scanned, it goes into a computer system and that data is stored in a database. Ideally, if the Imob scanners were used 100% of the time by passengers to validate their tickets, this would be very useful information for the computer model. However, only about 30% of all passengers actually validate their ticket before boarding the *vaporetti*.



The best way to ensure that the Imob system is collecting accurate data would be to install turnstiles at every Actv stop. Tickets would have to be scanned by the Imob in order for the turnstile to allow access. Turnstiles are installed in subways and other public transportation systems all over the world to prevent fare evasion for years, and it would certainly complement the Imob already installed in Venice. Even more accurate data could be obtained if turnstiles were also installed at the exit ramps at every Actv stop. This would allow the computer to analyze where passengers are getting off. The partnership between the Imob scanners and turnstiles would not only regulate traffic onto and off of the *vaporetti*, but allow for accurate Actv data collection.

5.3 Computer Model Recommendations

The long term scope of the Venice Project Center's mobility projects has always been to address the mobility issues within Venice and to work towards improving them. With this end goal in mind, the project team believes that the development of a fully functional computer model for the entire city of Venice will produce this desired result.

5.3.1 A Model Solution

A fully developed model has the potential to serve as a resource for government agencies and individual citizens. The prediction capabilities of a model will enable the City of Venice to take preventive rather than reactive measures to combat overcrowding and extreme traffic volume scenarios. The prediction capabilities, as well as the ability of the model to fill in data gaps, could allow Venetians to reroute themselves to avoid areas of high congestion, thus improving quality of life and helping to alleviate further congestion.

5.3.2 Collecting Data

Currently efforts to collect pedestrian traffic data are sporadic and expensive. Collecting data through field counts and interviews is very time consuming and leaves many of gaps in data. The team recommends that instead of continuing to put money into surveys and traffic studies, a software counting system is developed. Such a system would have the ability to conduct pedestrian counts from video surveillance feeds and would be able to do so with minimal human input. This data could then be fed continually into the model in order to increase the accuracy of traffic predictions. The use of such a system would render the need for other pedestrian traffic data collection unnecessary in certain locations. For instance, if the video counting system was implemented outside *traghetto* crossings, the need to conduct manual counts or surveys at those locations would be no more.

5.3.3 A Comprehensive Network

The creation of pedestrian counting software could also be paired with existing video surveillance hardware already in place throughout the city. A number of city controlled organizations and agencies already have camera systems in place for various purposes. All of these video feeds, if collected and coupled with the counting software, could be dual-tasked to provide valuable traffic data that could improve the model and as a result, mobility. Despite the multitude of cameras already in place, it is recommended that additional cameras be placed at other key locations to provide a comprehensive picture of mobility in the city.

5.4 Smart-Phone Application Recommendations

The development of an application for current popular smart-phone platforms would facilitate the travel of individuals within the city and improve the efficiency of mobility in the city. Furthermore, the use of such an application would prove to be a reliable source of data to include within the model.

5.4.1 Dual-Tasked Application

The application would ideally provide valuable information for both the user as well as for the agent-based computer model. In order to collect valuable information for the model, the application would need to have an easy-to-use interface which is both streamlined and informative to gather many users. The application would provide a plethora of maps, along with GPS location service to help the user find their location, and also provide directions to a desired location. This process would be valuable to tourists by preventing them from getting lost, as well as valuable to the local population by aiding them in avoiding traffic and efficiently planning their daily routes. A sample image of the interface for this process can be seen below, on the left figure.

Figure 56: Left, Example Smartphone Directions. Right, Time Table Interface

The user would have the ability to choose between multiple routes based on distance, time of travel, or even a preferred method of locomotion, such as walking or using mass transit. In addition, time tables for the *vaporetti* would be available to be viewed, as well as integrated into the trip planning features of the application. A sample image of the time table graphical user interface can be viewed above, on the right. This interface would aid in increasing the use of mass transit within the city, which may help alleviate traffic on land, directly aiding mobility. By planning these trips through the application, the model could be informed of the routes taken by users as another source for viable and accurate data. In addition, this data can be verified to be accurate by a ticket purchasing service, which would both confirm that the user will take the route outlined, in addition to providing the user with yet another convenience. The ticket purchased through the application would display a barcode with the ability to be scanned (seen in Figure 59), providing yet another means of confirmation that data received from the mobile device accurately describes reality.

Figure 57: Mass Transit Ticket with Barcode

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Appendices

Appendix A: Study Area Map

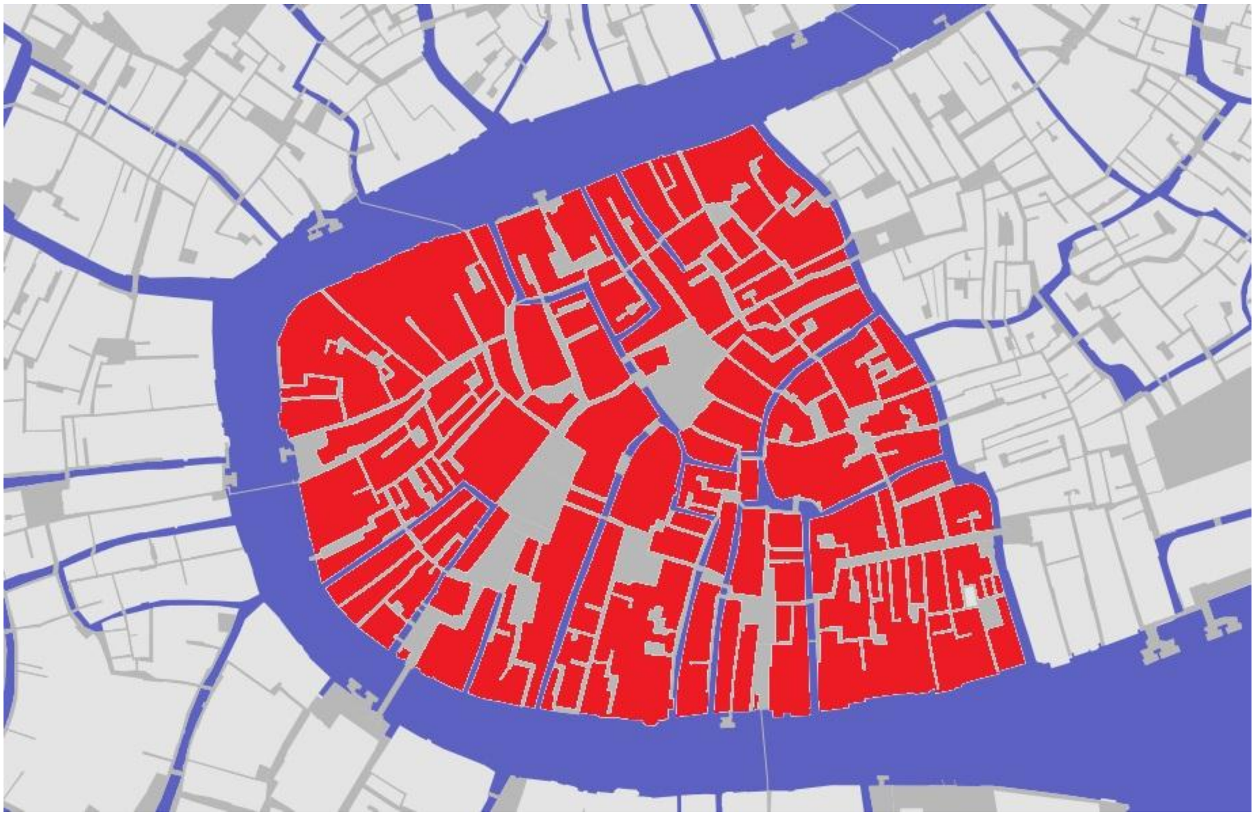

Figure 58: Map of the Study Area - Western Portion of San Marco

APPENDIX B: PEDESTRIAN TYPES FLOW CHART

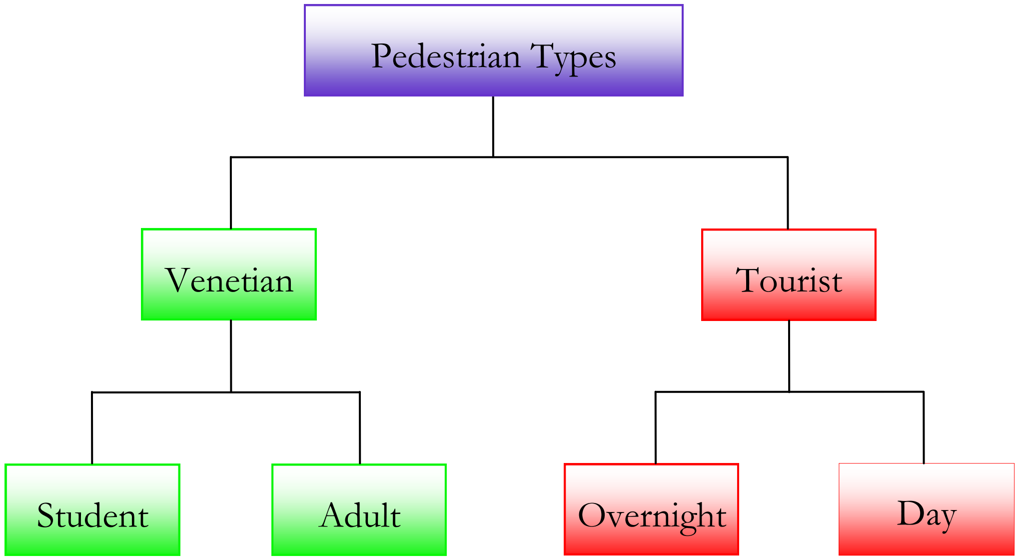

Figure 59: Flow Cart of Pedestrian Types

Appendix C: Map Layers

C.1 Study Area

Figure 60: GIS Map Layer of the 2011 Study Area

Figure 61: Google Map of the 2011 Study Area

C.2 Bridges

Figure 62: GIS Map Layer of the Bridges in Venice

C.3 Hotels

Figure 63: GIS Map Layer of the Hotels in Venice

C.4 Schools

Figure 64: GIS Map Layer of the Schools in Venice

Figure 65: Google Map of the Schools in Venice

C.5 Churches

Figure 66: GIS Map Layer of the Churches in Venice

C.6 Palaces

Figure 67: GIS Map Layer of the Palaces in Venice

Appendix D: Bridge Counts

These data are the project team's actual field counts recorded throughout the term. The counts were recorded by nodes, such as AB or FE, and days. A number after a node pair specifies a different day of counting.

D.1 *Ponte del Teatro*

Time	AB	AB2	BA	BA2
7:00	3		9	
7:15	9		15	
7:30	9		8	
7:45	18		15	
8:00	14		18	
8:30	14		18	
8:45	27		21	
9:00	22		25	
9:30	19		31	
11:45	16		13	
12:00	21		20	
12:45	13		13	
13:00	22		27	
13:30	17		22	
13:45	24	10	20	5
14:00	13	7	30	8
14:15	12		12	
14:30	51		6	
14:45	23		21	
15:00	18		27	
15:15	21		27	
15:30	11		23	
15:45	11		28	
16:15	21		16	
16:30	21		25	
16:45	17		20	
17:00	15		22	
17:30	11		11	

D.2 *Ponte de San Paternian*

Time	CD	CD2	DC	DC2
7:00	1		2	
7:15	1		4	

7:30	0		0	
7:45	4		4	
8:00	2		6	
8:30	4		2	
8:45	5		6	
9:00	14		11	
9:30	6		7	
11:15	8		0	
11:45	3		3	
12:00	5		3	
12:45	7		2	
13:00	3		7	
13:30	7		15	
13:45	20		3	
14:00	13		3	
14:15	7		3	
14:30	1		13	
14:45	0	6	7	8
15:00	9		8	
15:15	4	8	5	2
15:30	6		15	
15:45	10	10	24	41
16:15	13		9	
16:30	2		9	
16:45	3		20	
17:00	5		2	
17:30	14		4	

D.3 *Ponte de la Cortesia*

Time	EF	EF2	EF3	EF4	Avg. Wkday	Avg. Wkend	FE	FE2	FE3	FE4	Avg. Wkday	Avg. Wkend
7:00	13				13		17				17	
7:15	22				22		26				26	
7:30	52				52		41				41	
7:45	49				49		91				91	
8:00	65				65		65				65	
8:30	96				96		71				71	
8:45	70				70		112				112	
9:00	91				91		86				86	
9:30	98				98		87				87	

11:15	110				110		132				132	
11:45	178				178		149				149	
12:00	177	246			177	246	198	135			198	135
12:45	118				118		151				151	
13:00	204	146			204	146	172	111			172	111
13:30	264				264		179				179	
13:45	180	176			178		199	132			165	
14:00	303	181			484		133	90			112	
14:15	235				235		103				103	
14:30	298				298		170				170	
14:45	281	152			216		126	92			109	
15:00	166	213			166	213	112	127			112	127
15:15	112	247			112	247	158	147			158	147
15:30	156	245	143		149	245	104	177	131		117	177
15:45	215	234	157		186	234	134	149	129		131	149
16:00	181				181		144				144	
16:15	234	271	188		211	271	118	173	138		128	173
16:30	206	352	290	218	212	321	164	199	172	111	137	185
16:45	182	277	312	205	193	294	166	150	139	140	153	144
17:00	187	301	193		190	301	128	145	105		116	145
17:15	249	252			252	249	162	167			167	162
17:30	222	227	229		225	227	123	151	138		130	151
17:45	205					205	120					120
18:00	195				195		124				124	
18:15	170				170		109				109	

D.4 *Ponte San Moisè*

Time	KL	KL2	KL3	Avg. Wkday	Avg. Wkend	LK	LK2	LK3	Avg. Wkday	Avg. Wkend
7:15	18			18		19			19	
7:30	14			14		31			31	
7:45	45			45		54			54	
8:00	46			46		41			41	
8:15	64			64		70			70	
9:15	232			232		99			99	
11:30	324			324		350			350	
11:45	285			285		381			381	
12:00	300	220		300	220	344	321		344	321
1:00	301	234		301	234	315	275		315	275
1:15	439	248		344		358	348		353	
1:30	293			293		375			375	

1:45	345	252		298		446	345		395	
2:00	332	242	279	287	279	545	370	360	457	360
2:15	302	382		342		432	256		344	
2:30	358			358		547			547	
2:45	354	242		354	242	539	300		539	300
3:00	356	233		356	233	478	327		478	327
3:15	242	292		242	292	244	345		244	345
3:30	184	315		184	315	256	481		256	481
3:45	211	362		211	362	275	482		275	482
4:00	223	303		223	303	326	374		326	374
4:15	287	275		287	275	304	515		304	515
4:30	254			254		355			355	
4:45	242	341		242	341	289	465		289	465
5:00	310				310	598				598
5:15	211	382		211	382	276	542		276	542
5:30	358				358	600				600
5:45	322				322	536				536
6:00										
6:15	261				261	456				456
7:00	210				210	424				424
8:00	215				215	410				410

Appendix E: *Traghetti* Counts

E.1 Carbòn

Date	Arrival Time	Count	Departure Time	Count
7-Nov	8:04	6	8:05	1
	8:08	6	8:09	0
	8:12	8	8:13	10
	8:17	12	8:19	2
	8:21	6	8:23	2
	8:26	8	8:27	3
	8:31	6	8:33	4
	8:36	12	8:37	2
	8:41	12	8:42	2
	8:45	8	8:46	1
	8:49	6	8:51	3
	8:54	7	8:56	2
	8:59	12	9:02	2
	9:06	10	9:07	2
	9:11	10	9:13	2
	9:17	12	9:19	1
	9:22	12	9:24	3
	9:27	11	9:29	4
	9:33	12	9:36	4
	9:41	8	9:43	7
	9:47	9	9:49	2
	9:52	12	9:54	2
	9:58	12	10:00	4
	10:04	12	10:06	2
	10:10	6	10:11	4
	10:16	9	10:17	12
	10:21	9	10:23	10
	10:27	10	10:28	8
	10:32	8	10:34	4
	10:38	10	10:40	4
	10:42	3	10:44	4
	10:47	12	10:50	3
	10:53	2	10:55	3
	10:58	4	11:01	10
8-Nov	11:21	6	11:16	5
	11:29	1	11:23	6
	11:36	4	11:31	7

	11:41	3	11:38	4
	11:50	3	11:46	3
	11:57	2	11:53	1
	12:03	2	11:59	1
	12:11	1	12:06	1
	12:19	5	12:15	4
	12:25	1	12:21	2
	12:33	1	12:28	1
	12:46	0	12:34	3
	12:55	2	12:48	2
	12:59	2	12:55	1
Totals		335		170

E.2 Sant'Angelo

Date	Arrival Time	Count	Departure Time	Count
7-Nov	7:32	13	7:34	3
	7:36	14	7:42	8
	7:44	14	7:47	1
	7:49	14	7:52	4
	7:54	15	7:57	10
	8:00	15	8:05	15
	8:08	15	8:11	15
	8:15	15	8:18	9
	8:24	14	8:26	11
	8:31	13	8:33	5
	8:39	14	8:42	9
	8:46	14	8:50	11
	8:53	14	8:56	5
	8:59	14	9:02	3
	9:05	14	9:08	11
	9:11	15	9:13	3
	9:18	15	9:21	9
	9:23	14	9:25	6
	9:31	14	9:34	9
	9:37	14	9:39	8
	9:45	14	9:47	8
	9:50	14	9:54	7
	9:58	15	10:01	7
	10:04	12	10:07	5
	10:11	13	10:14	2

	10:17	15	10:20	9
	10:24	14	10:27	5
	10:24	14		
	10:30	15		
8-Nov	11:02	9	11:05	11
	11:09	12	11:12	12
	11:15	13	11:18	6
	11:21	12	11:24	8
	11:26	13	11:29	5
	11:32	7	11:34	8
	11:37	3	11:40	7
	11:42	9	11:45	5
	11:48	3	11:50	7
	11:55	12	11:58	8
	12:05	2	12:08	9
	12:12	3	12:15	8
	12:20	4	12:22	4
	12:26	4	12:28	7
	12:34	7	12:36	7
	12:43	6	12:46	5
	12:48	7	12:50	4
	12:53	8	12:55	1
	12:57	5	12:59	2
	13:01	7	13:03	4
	13:05	0	13:08	10
	13:11	13	13:13	7
	13:15	2	13:17	4
	13:20	8	13:22	5
	13:24	7	13:26	4
	13:30	3		
	13:50	7		
	13:57	10	13:58	12
	14:06	14	14:07	9
	14:14	7	14:15	7
	14:21	10	14:22	1
	14:30	11	14:31	17
	14:38	12	14:39	12
	14:47	12	14:48	9
	14:50	10	14:51	9
	14:55	14	14:56	4
	15:02	3	15:03	5
	15:09	9	15:10	14
			18:02	2

	18:06	4	18:10	6
	18:13	10	18:16	7
	18:18	3	18:22	6
	18:24	11	18:26	4
	18:28	11	18:30	4
	18:33	8	18:37	1
	18:39	4	18:43	0
	18:45	6	18:48	3
	18:50	4	18:54	0
	18:56	3	19:00	0
	19:02	5	19:04	0
	19:07	1	19:10	0
	19:13	1	19:15	0
Totals		779		488

E.3 San Samuele

Date	Arrival Time	Count	Departure Time	Count
7-Nov	8:30	0	8:31	0
	8:34	6	8:39	1
	8:42	5	8:50	1
	8:55	4	8:58	0
	9:01	5	9:06	2
	9:10	8	9:11	1
	9:15	12	9:18	1
	9:22	4	9:24	2
	9:29	5	9:30	3
	9:33	2	9:34	5
	9:38	2	9:43	0
	9:46	6	9:48	1
	9:52	5	9:53	0
	9:58	8	10:00	2
	10:03	3	10:04	4
	10:10	7	10:12	2
	10:15	2	10:17	1
	10:19	2	10:22	2
	10:26	2	10:27	2
	10:32	7	10:32	2
	10:38	4	10:39	2
	10:43	1	10:45	2
	10:48	11	10:50	4

	10:55	2	10:56	5
8-Nov	11:01	3	10:59	2
	10:54	1	11:14	1
	11:13	1	11:28	1
	11:26	2	11:39	2
	11:33	2	11:47	2
	11:44	3	11:54	4
	11:53	1	12:02	3
	11:59	1	12:10	4
	12:09	2	12:36	2
	12:18	6	12:48	1
	12:45	2	12:54	5
	12:52	2	13:07	3
	13:03	1	13:15	1
	13:14	0	13:19	0
	13:18	1	13:30	0
	13:24	6		
Totals		147		76

Appendix F: *Traghetti* Percentage Charts

These figures demonstrate the differences between the quantity of passengers arriving and departing the study area at a certain *traghetto* stop.

F.1 Carbòn

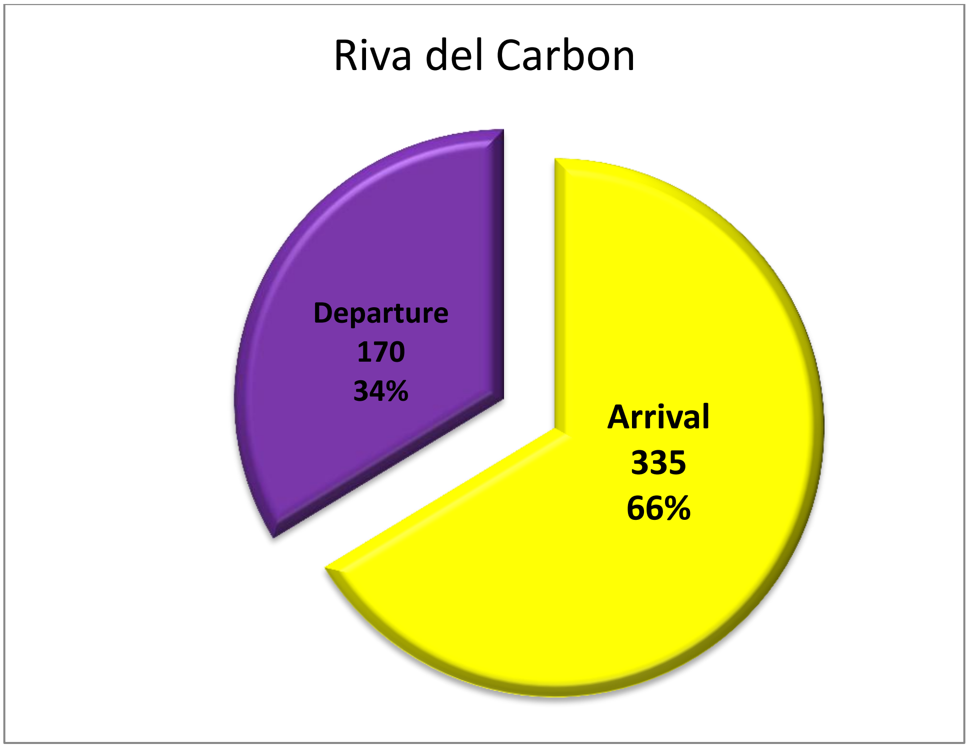

Figure 68: Percentage Chart for Carbòn

F.2 Sant’Angelo

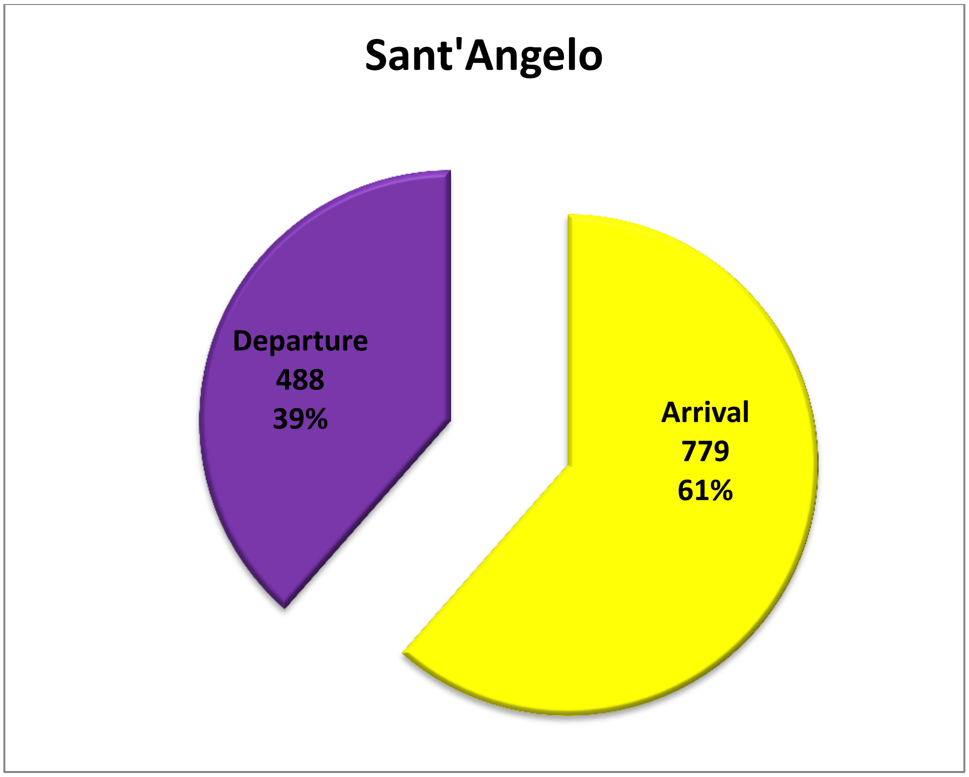

Figure 69: Percentage Chart for Sant'Angelo

F.3 San Samuele

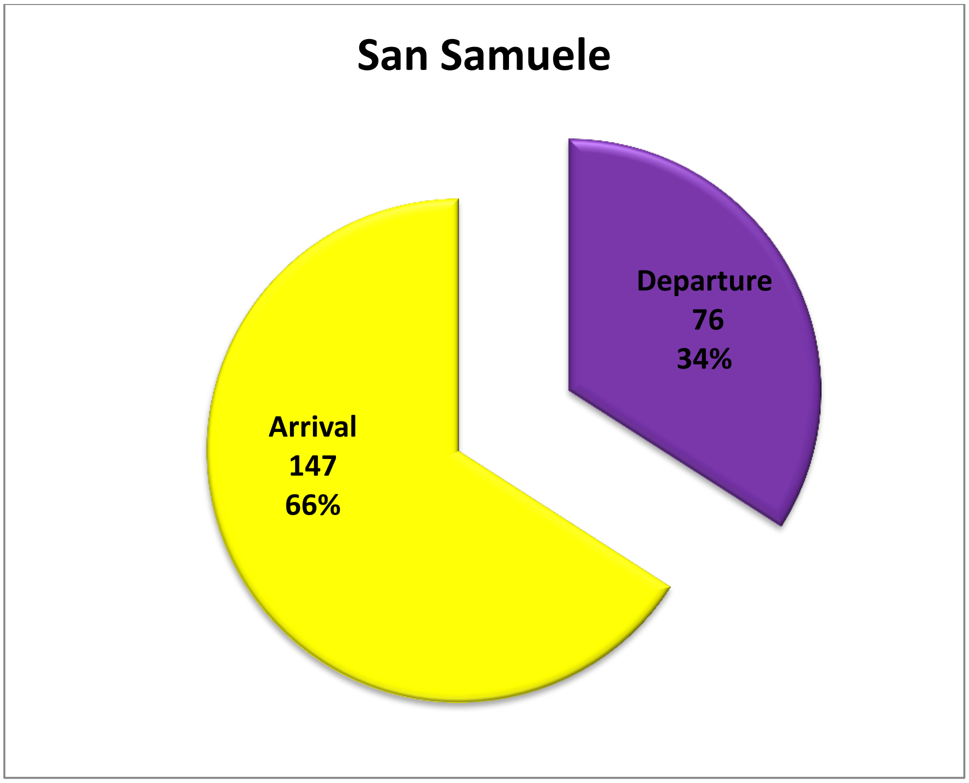

Figure 70: Percentage Chart for San Samuele

Appendix G: Agent Breakdown Data

Key: Chelsea Fogarty (CF), Geordie Folinas (GF), Steven Greco (SG), Cassandra Stacy (CS)

G.1 *Ponte de la Cortesia* 17-Nov

Time	GF Count	SG Count	CS Count	Average Count	CF Total Pedestrian Count	% Tourists
8:00	10	12	4	8.666666667	115	7.536231884
8:15	4	8	3	5	151	3.311258278
8:30	7	6	7	6.666666667	166	4.016064257
8:45	19	14	12	15	192	7.8125
9:00	38	34	51	41	195	21.02564103
9:15	12	21	16	16.33333333	204	8.006535948
9:30	17	27	40	28	228	12.28070175
9:45	27	27	22	25.33333333	200	12.66666667
16:00	54	46	62	54	253	21.34387352
16:15	80	75	85	80	304	26.31578947
16:30	110	86	57	84.33333333	338	24.95069034
16:45	141	84	56	93.66666667	296	31.64414414

G.2 *Ponte San Moisè* 18-Nov

Time	GF Count	SG Count	CS Count	Average Count	CF Total Pedestrian Count	% Tourists
8:00	9	11		10	93	10.75268817
8:15	26	34	9	23	138	16.66666667
8:30	45	36	18	33	156	21.15384615
8:45	52	47	27	42	189	22.22222222
9:00	73	62	53	63	245	25.57823129
9:15	98	89	83	90	288	31.25
9:30	108	116	88	104	304	34.21052632
9:45	131	127	116	125	336	37.1031746
10:00	153	158	132	148	378	39.06525573
16:00	345	282	261	296	462	64.06926407
16:15	349	345	287	327	517	63.24951644
16:30	407	368	289	354.6666667	541	65.55760937
16:45	417	366	312	365	523	69.78967495
17:00	384	369	293	348.6666667	494	70.5802969
17:15	410	356	212	326	435	74.94252874
17:30	265	177	233	225	385	58.44155844
17:45	255	216	227	232.6666667	453	51.36129507

G.3 *Ponte dell'Accademia* 22-Nov

Time	GF Count	SG Count	CS Count	Average Count	CF Total Pedestrian Count	% Tourists
8:00	5	8	0	4.333333333	213	2.034428795
8:15	7	7	4	6	307	1.954397394
8:30	14	11	17	14	190	7.368421053
8:45	8	7	7	7.333333333	222	3.303303303
9:00	13	9	8	10	197	5.076142132
9:15	32	27	30	29.66666667	228	13.01169591
9:30	28	24	19	23.66666667	239	9.90237099
9:45	38	69	48	51.66666667	272	18.99509804
16:00	87	65	104	85.33333333	370	23.06306306
16:15	79	141	105	108.3333333	357	30.34547152
16:30	110	94	96	100	300	33.33333333
16:45	117	94	83	98	345	28.4057971
17:00	114	103	92	103	360	28.61111111
17:15	128	143	113	128	433	29.56120092
17:30	86	67	64	72.33333333	298	24.27293065
17:45	71	80	51	67.33333333	305	22.07650273

APPENDIX H: VIDEO COUNTS

These counts are the manual counts taken from video clips and used to verify the field counts taken at the time of the video. The "Rightward" and "Leftward" columns contain the number of pedestrians counted on site, simultaneous with footage capture, moving in that direction respective to the camera.

Key: "Rightward" is towards the Accademia for the *Ponte dell'Accademia* clips, and towards *Chiese San Moisè* for the *Ponte San Moisè* clips. "Coming" is towards San Marco, and "Going" is away from San Marco for the verification counts. As the camera setup differed slightly at each bridge because the orientation had to be changed to not obstruct traffic, "Rightward" is equivalent to "Coming," and "Leftward" is equivalent to "Going."

H.1 Video Sample Descriptions

Table 10: Quantitative Video Clips

Video Name	Date	Location	Length	Rightward	Leftward	Total Count
Ve11_Mobility Footage_1	15/11/11	*Ponte dell'Accademia*	15:30	180	144	324
Ve11_Mobility Footage_2	15/11/11	*Ponte dell'Accademia*	16:00	210	201	411
Ve11_Mobility Footage_3	15/11/11	*Ponte dell'Accademia*	16:30	229	138	367
Ve11_Mobility Footage_4	14/11/11	*Ponte San Moisè*	15:45	209	204	413
Ve11_Mobility Footage_5	15/11/11	*Ponte dell'Accademia*	17:00	232	150	382
Ve11_Mobility Footage_6	16/11/11	*Ponte de San Paternian*	15:05	6	8	14
Ve11_Mobility Footage_7	16/11/11	*Ponte de San Paternian*	15:27	8	2	10
Ve11_Mobility Footage_8	16/11/11	*Ponte de San Paternian*	16:08	7	42	49
Ve11_Mobility Footage_9	16/11/11	*Ponte de la Cortesia*	15:02	155	93.5	248.5
Ve11_Mobility Footage_10	14/11/11	*Ponte de la Cortesia*	31:39	142	143	285

H.2 Quantitative Video Counts

Key: Field Count (FC), Manual Count (MC)

Table 11: Manual Verification Counts from Video Feed

Video Name	Coming Avg.	Going Avg.	MC Total	FC Coming	FC Going	FC Total	Statistical Difference
Ve11_Mobility Footage_1	151.5	187	338.5	144	180	324	4.4753
Ve11_Mobility Footage_4	207	196.5	403.5	209	204	413	2.3002
Ve11_Mobility Footage_6	6	8	14	6	8	14	0
Ve11_Mobility Footage_7	8	2	10	8	2	10	0
Ve11_Mobility Footage_8	7	42	49	10	41	51	3.9216
Ve11_Mobility Footage_9	155	93.5	248.5	152	92	244	1.8443
Ve11_Mobility Footage_10	142	143	285	143	131	274	4.0146
Ve11_Mobility Footage_10	159	133.5	292.5	157	129	286	2.2727

APPENDIX I: STUDY AREA BRIDGE LOCATIONS AND NODES

2011 Bridges Analyzed	Node	Latitude (Deg)	Longitude (Deg)
Ponte del Teatro	AB	45.435616	12.333586
Ponte de San Paternian	CD	45.435289	12.333827
Ponte de la Cortesia	EF	45.43514	12.333902
Ponte dei Barcaroli o del Cuoridoro	GH	45.434194	12.3348
Ponte de Piscina	IJ	45.433898	12.334937
Ponte San Moisè	KL	45.433065	12.335566
Ponte dell'Accademia	MN	45.431691	12.328939