



Turning Traffic Around: An Analysis of Boat Traffic in Venice and its Environmental Impacts

An Interactive Qualifying Project Report
Submitted to the faculty
of the

Worcester Polytechnic Institute

In partial fulfillment of the requirements for the
Degree of Bachelor of Science

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Thursday 14 December 2007

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This project was completed with the equal participation of each team member. Without full cooperation and effort provided by each team member, this project could not have been successfully completed.

Acknowledgements

- We would like to thank the members of our families whose support made it possible for us to take advantage of this wonderful opportunity.
- Thanks to our advisors, Sensei Fabio Carrera and Professor Kristen Billiar, for their time and patience throughout.
- Thanks to the staff at Forma Urbis, Daniela Pavan, Andrea Novello, and Alberto Gallo for taking their time to help us out behind the scenes.
- We are grateful to the Redfish group for letting us use their model and for their insight into complex traffic analysis.
- Thanks to COSES and ARPAV for making their field data available for use in our project.
- We acknowledge the work of the Moto Ondoso Index project team.
- A special thanks to “Coffee Guy” for providing the best espresso we’ve ever had, to the good people of C’e` Pizza e Pizza for being open Sunday nights when nothing else was, and to the wonderful ladies at the Crazy Bar for not charging to eat in.

Abstract

This project contributed to the ongoing development of an autonomous agent model of Venetian boat traffic by collecting detailed turning-movement counts at 17 intersections and updated indices for boat produced noise and wake pollution. These intersections had never before been studied nor had any of their traffic-related environmental concerns been assessed. The team identified the major contributors of each pollution type and recommended speed limit enforcement and more efficient traffic regulation as methods by which to mitigate potential environmental concerns.

Executive Summary

Venice has a unique traffic system in that the primary means of vehicular transportation is boats. This, however, does not exempt Venice from some of the same problems that the average major city faces. Like other cities, Venice is subject to traffic-related noise pollution and congestion. Unique to Venice, though, is Moto Ondoso, otherwise known as wake pollution, which has the “destructive potential to sink the city.”¹

Traffic count studies pioneered by WPI are undertaken semiannually by COSES, a city organization dedicated to research and advancement. These counts facilitated our analysis which, in the future, will allow city officials to make more informed decisions regarding traffic restriction and regulation. Data concerning noise and wake pollution output by boat type has been taken in various studies in Venice. Not much has come of the collected data and little environmental analysis has been completed.

The project group sought to increase the amount of traffic knowledge by conducting additional field counts at previously uncounted locations. Combining this information with past traffic count studies, the group increased the accuracy of current Venetian traffic models and

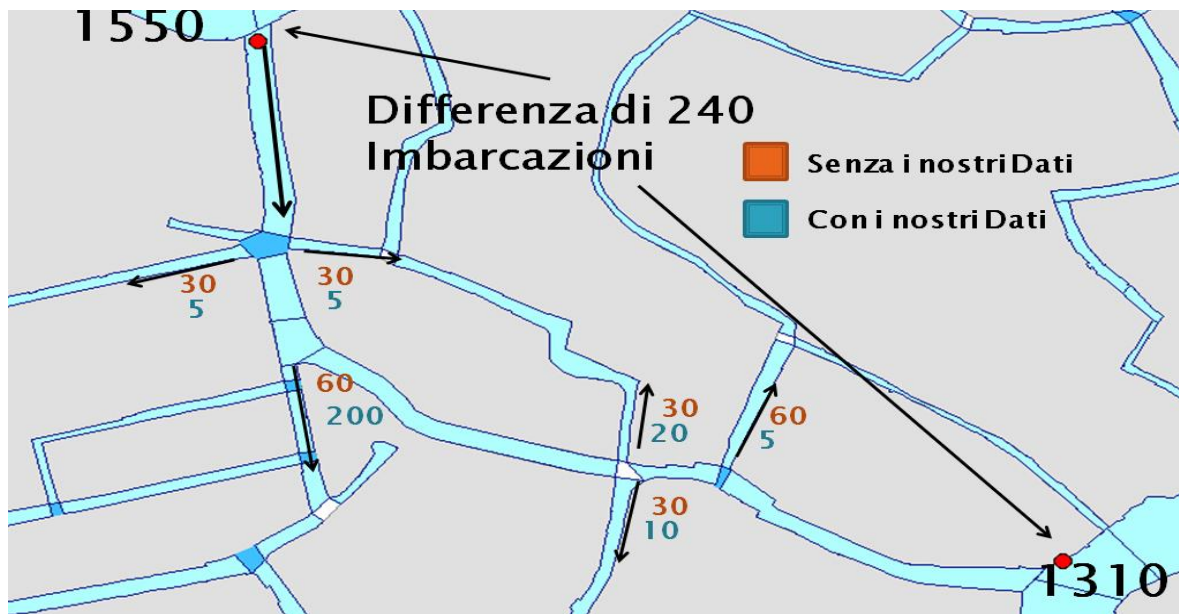


Figure 1: Map shows increased accuracy with the addition of our data

investigated the environmental impacts of traffic. The picture above displays a difference of 240 boats between two major counting locations. Without field data at potential turning points in between, a model would have to guess how the boats distributed in order to account for the

¹ Professor Fabio Carrera

disparity. Instead of inaccurately assigning equal value to each intermediate intersection, the correct number of boats that turned at each location can be used due to field data collected by the project team.

The traffic count locations were selected based on the criteria that they are integral to inner canal traffic flow and had not yet been counted. Working in groups of two, we counted boats in accordance with the methodology created by WPI and presently employed by COSES. Working during peak traffic hours, boats and their maneuvers were counted and categorized by type.

Using past traffic count studies alongside existing noise and moto ondosso pollution data, the group calculated index values for each pollution type at various locations throughout the canal system. These values were quantitatively ranked and used to create gradient maps presenting areas of high and low pollution. This moto ondosso gradient map shows areas of high (red) and low (yellow) wake pollution. As might be expected, the highest levels of wake pollution are along the Grand Canal and Rio Novo.

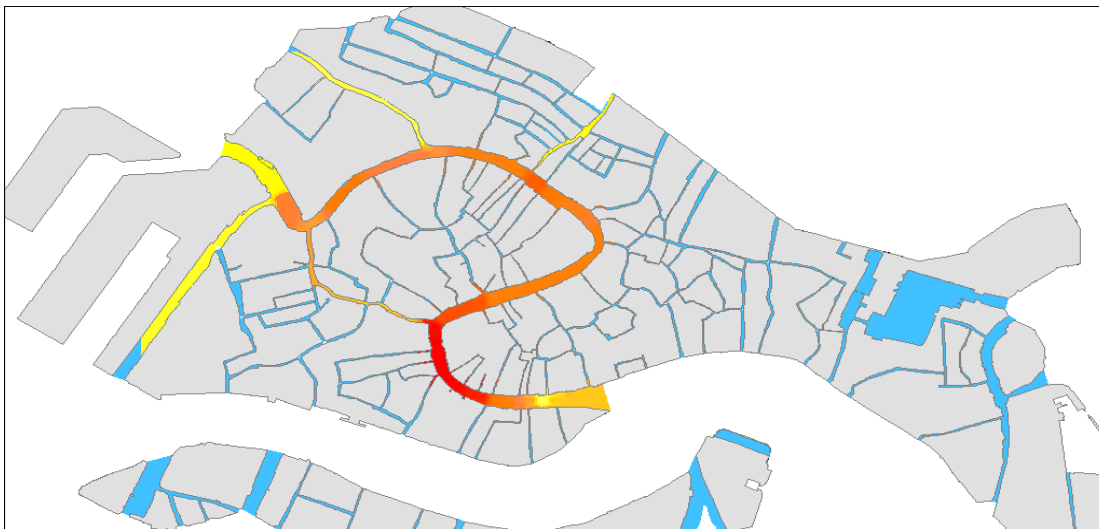


Figure 2: Moto ondosso gradient map

It was determined that boat traffic volume is not necessarily directly proportional to the amount of pollution in any given area. For example, pollution impacts of ten *gondole* and ten cargo ships are quite different. While the *gondole* contribute heavily to traffic congestion, they produce virtually no pollution. Conversely, *turismo* boats generally travel at high speeds and contribute a high percentage of the total pollution.

These pie charts present the percentage contribution by boat class to total traffic side by side with the percentage contribution to moto ondosso pollution. *Turismo* boats account for only

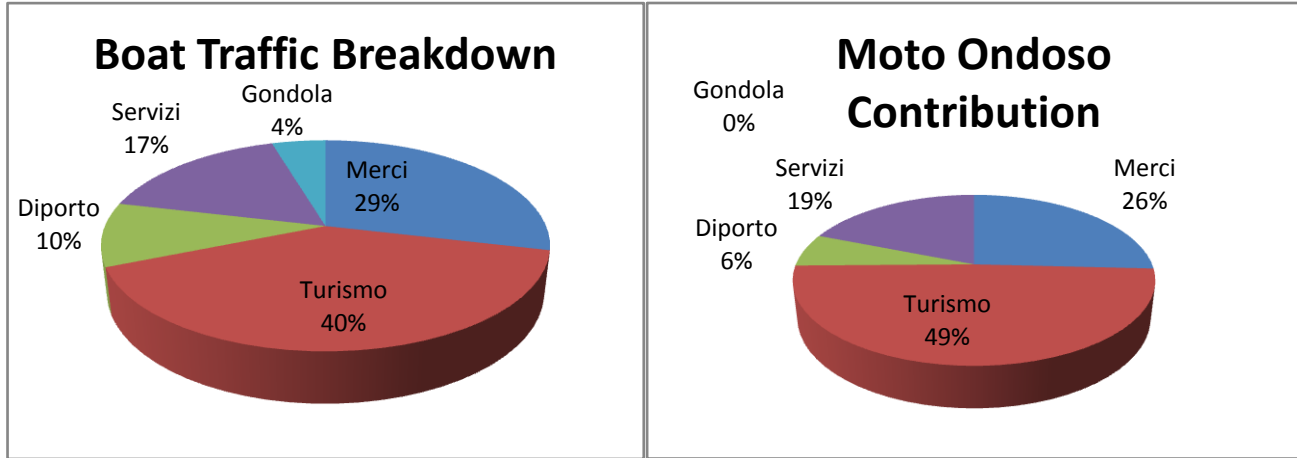


Figure 4: Noise pollution by boat class

Figure 3: Moto ondosso contribution by class

40% of the total traffic and yet they are responsible for nearly half of the canal system's wake pollution.

The environmental effects of traffic can be easily mitigated through improved regulation and stricter law enforcement. The project group concluded that excessive speed is a majority contributor to boat-produced noise and wake pollution. Further study evaluating specific pollution contribution by boat type would be instrumental in better understanding the cause of, and solution to, traffic related environmental concerns. Additionally, the project group recommends additional seasonal traffic count studies be undertaken as they provide the foundation upon which all other traffic related issues may be meaningfully analyzed.

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1. Introduction

City traffic is considered most often in terms of heavy congestion as a result of the work commute. This pattern is referred to as the origin/destination traffic model. The traffic is, in turn, simulated with this in mind. Unregulated traffic would pose a serious threat both to people and to the environment. Therefore traffic laws, regulations, and speed limits are often investigated and



Figure 5: Typical traffic congestion²

altered. Traffic is often overlooked but it is very much an integral part of the city. For example, Washington D.C. experiences a 73% population increase as a result of non-resident traffic.³

Venice is no different from other major cities of the world in that traffic directly affects every facet of daily life.

There is, however, one unique divergence. Cars are not allowed in Venice; all of the city's vehicular traffic is due to boats. While some aspects of typical traffic considerations apply, many do not. Venice is interwoven with nearly 150 canals through which boats travel daily.⁴ A thorough understanding of this boat traffic can lead to vast improvements throughout the city. Similar to car traffic, boats also pollute the environment. The most prevalent forms of such pollution are water, noise, and wake.

Water traffic results in a variety of potential dangers which, when better understood, can be reduced to an acceptable level. Previous research has measured some of these dangers. By determining the average energy output and volume of boats by type at various locations, an index was created that identifies areas of high wake pollution. In addition, ARPAV observed boats at various locations and recorded their decibel outputs at various speeds and accelerations during a

² http://truckphotos.freesevers.com/traffic_jam.jpg

³ http://money.cnn.com/2005/10/21/real_estate/buying_selling/daytime_population_cities

⁴ Carrera, Fabio and Caniato, Guiovanni; "Venezia la Citta Dei Rii

sixteen hour period. Finally, traffic counts are taken semiannually at over twenty locations throughout the city (Figure 17).

Traffic count data has yet to be taken at many intermediate canal intersections. Though data exists for high traffic intersections, there is insufficient data to accurately simulate traffic behavior through the inner canals. To this end, boat traffic counts at the inner canals would increase knowledge about traffic flow through the entire network. Currently, a team from the Santa Fe Institute is developing an autonomous agent model which relies



Figure 6: Venetian traffic congestion

heavily upon traffic data to accurately simulate the manner by which boats navigate the canals. With a better understanding of Venice's traffic, the previously collected pollution data can be used as a proxy to evaluate the environmental impacts of said traffic.

The most recent traffic count data will be used to update the moto ondosso index and to create a noise pollution index. With the addition of our traffic counts, our goal is that the autonomous model will become more intelligent and allow us to construct precise pollution indices based on more realistic numbers. Additionally, an accurate simulation is invaluable in cases of emergency planning and can be used more broadly to increase traffic efficiency.

2. Background

The project team studied boat traffic at intermediate canals in Venice and its environmental impacts. In order to become more familiar with these topics the team researched some general information about Venice, boats, traffic, and related types of pollution. Included in Section 2 are important topics relevant to boat traffic counts, boat pollution, and the Venetian canal system.

2.1 Traffic

For centuries Venetians sole mode of transport through the canal system was human powered boats. Seeing as rowboats create no wake pollution, the possibility of erosion leading to collapse was never taken into consideration. However, since the advent of motor boats, the population of rowboats has become nearly extinct. Waterborne traffic as a primary means of transportation has lead to a unique traffic paradigm.

Traffic patterns are primarily influenced by origin and destination. For instance, traffic in a major city depends most heavily upon the commute to and from work. Weekend and afternoon traffic are predisposed more towards leisure and consumer activities. Venice traffic, though, is significantly different from that which most experience. Residents of Venice commute to work on foot or by means of public transportation. For this reason, Venetian traffic does not fit the typical model. The traffic in Venice that fits the origin-destination model is characterized by the delivery of goods to stores which accounts for 36% of Venice's traffic.

A significant portion of Venice's traffic results from taxis. In fact, taxi/public transportation accounts for 46% of the total traffic.⁵ This is almost completely fueled by the tourism industry, which provides Venice with 70% of its yearly income. With 18 million tourists every year and growing, there has never been more stress put on the environment and Venice's 150 canals.⁶

2.2 Venetian Boat Types

The many boats travelling daily through the canals in Venice fit categorically into 21 types as seen in Appendix B. It is important to categorize them this way as they serve different purposes and contribute differently to pollution.



Figure 7: Cargo boat (Type 2)

The first two types are reserved for cargo boats, large and small respectively. Similar to delivery trucks on the highway, these cargo boats travel the same routes over and over again delivering items throughout the city. For considerations of traffic analysis, they are linked together in a class named cargo.



Figure 8: Taxi (Type 3)

The third type of boat, taxis, accounts for a

⁵ Carrera, Fabio and Caniato, Guiovanni; "Venezia la Citta Dei Rii"

⁶ <http://news.bbc.co.uk/2/hi/europe/6035047.stm>

significant portion of inner canal boat traffic. Due to the extremely high level of tourism in Venice, taxis are kept permanently busy traveling back and forth between the airport and hotels. The economy of Venice relies heavily on the canal system as it is the primary method of tourist transportation and sightseeing.⁷ Their business is increased more so by the greatly reduced speed of alternate travel methods. Taxis are particularly notorious for travelling quickly with large payloads and averaging a higher noise output than other boat types. Taxis belong to the public transportation class.

The remaining members in the public transportation class are larger boats that travel between designated stops according to schedule. The vaporetta, motoscafi, and alilaguna boats belong to this category.



Figure 9: Personal boat (Type 6)



Figure 10: Gondola (Type 20)

Before their existence, gondolas were employed to transport people across Grand Canal and to the mainland.⁸

Not all boats travelling through the Venetian canal system are for public transportation. Privately owned sport boats can be seen as well, albeit less frequently. Types six and seven are reserved for personal boats with and without cabins, respectively. They are generally quite small in comparison, manned by one or two people, and have a tendency to travel more quickly than other larger boats. Unlike cars in a city, private transport is representative of a great minority. Even native Venetians opt to travel publicly in lieu of using their own boats to and from work.

The final boat class, gondola, is intrinsically associated with Venetian history. Today, gondolas are employed primarily by tourists for city tours. Gondolas are unique also in that they represent the largest population of non-motorized boats still operation in Venice. Motorboats are responsible in large part for the environmental harms of neither of the above and are a constant reminder of Venice's serene past.

⁷ "Monitoring and Analysis of Cargo Delivery Systems in Venice, Italy" IQP. pp. 3-4

⁸ "Evaluation of Tourist Use of Venetian Transportation", IQP 2001. pp. 28-30

2.3 Traffic Count Studies

Between February, 1992 and July, 1994, WPI students completed projects that collected traffic data in several major canals in Venice. This study included a count of boat passages per day and included specifications on boat type and approximate

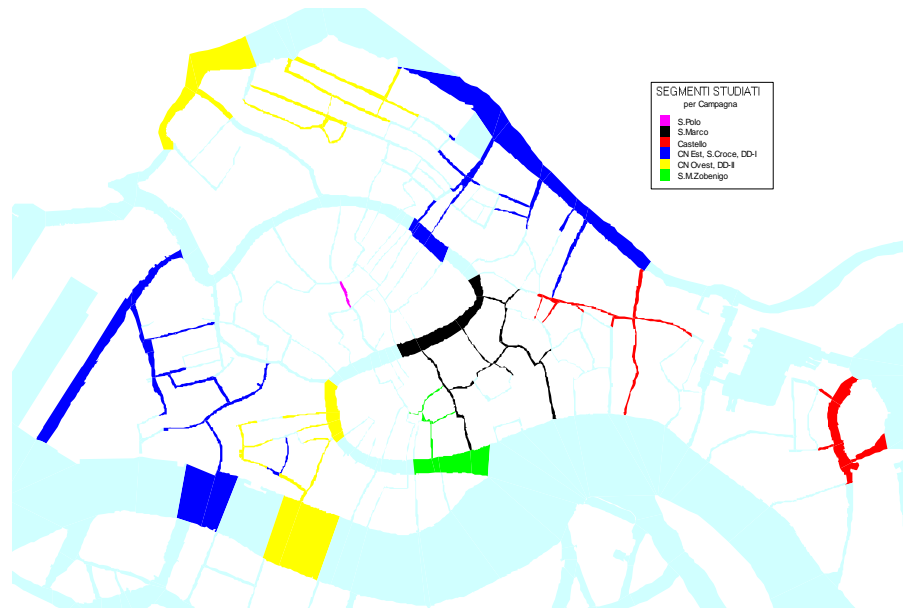


Figure 11: Boat traffic index completed by WPI students between the years of 1992 and 1994

payload.⁹

Since then, WPI has pioneered traffic counts throughout the city on a semiannual basis. Now, counts are taken by a city organization named COSES. The purpose of these counts is to better understand and evaluate traffic flow. In doing so, the city will be better prepared to make policy recommendations regarding traffic.



Figure 12: Moto ondosso damage

⁹ Carrera, Fabio; Il Traffico Acqueo Nei Canali Interni Di Venezia, 10, Luglio, 1996.

2.4 Moto Ondoso Index

Canal wall deterioration is catalyzed by boat wakes. The waves slowly erode the walls and the mortar which binds them. This compromises the structural integrity of the walls such that they are more susceptible to the destructive forces of boat wakes.

After World War II, the population of motorized boats in the canals of Venice increased rapidly. Before motorboats were introduced into the canal system, the canal walls were only subjected to the forces of water as it flowed in and out of the lagoon with the tides. Because motorboats have since become the primary mode of transportation in the city, the canal walls have been exposed to the constant friction caused by boat wakes.

When a boat moves through an area it first displaces the water by pushing it away from the boat. Then, as it leaves the same area, a gap in the water is left which is quickly filled in by gravity's effect on the surrounding water. This disturbance creates a wake, which can be devastatingly erosive to nearby structures. In general, this is not a problem because the energy can disperse in large bodies of water. In the canals, however, where the width and depth is severely limited, this poses much more of a problem when the energy from the wakes is transferred into the canal walls.

In addition to the wake produced by passing boats, a significant amount of turbulence is created during maneuvers. Unlike cars, boats do not have brakes and are required to reverse their engines in order to slow down. In doing so, they increase their turbulence output by churning water beneath the surface.



Figure 13: Example of wake pollution from a taxi

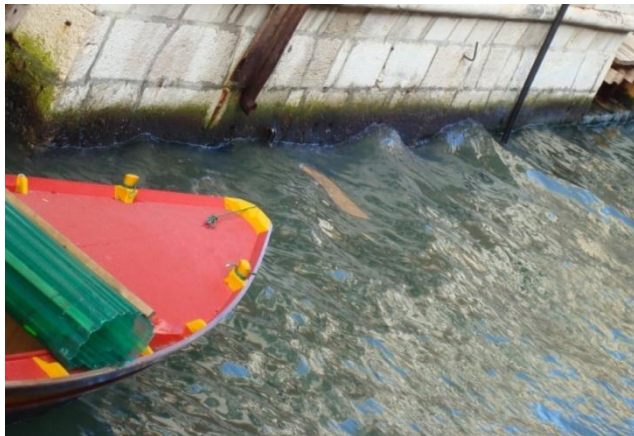


Figure 14: Example of wake pollution against canal walls

The erosion of the canal walls raises an immediate concern to the structures on and around them. There have been many instances of buildings collapsing due to their structures being eroded from beneath them. Not only is this a safety issue, but the city faces the danger of losing some of its historical beauty.

Wake pollution is rapidly becoming an unavoidable issue. The repair of the walls is quite expensive, ranging anywhere from 100 to 3000 Euros.¹⁰ Compared to motorized boats, human powered boats create little to no wake. Intuitively, wake pollution has become a problem since the use of motorboats increased. The speed at which boats travel has a direct impact on the amount of wake they produce.¹¹ There has been research done demonstrating that a drastic reduction in wake pollution can be achieved if boats traveled at the posted speed limits.¹²

In 2002, a group of WPI students measured moto ondosso over a seven week period in an attempt to quantify wake pollution by boat type. They did this by measuring wake period, wavelength, and amplitude, as well as average speed by boat type. Then, the average moto ondosso output by boat type was calculated in order to determine a rough estimate of which canals were most affected.

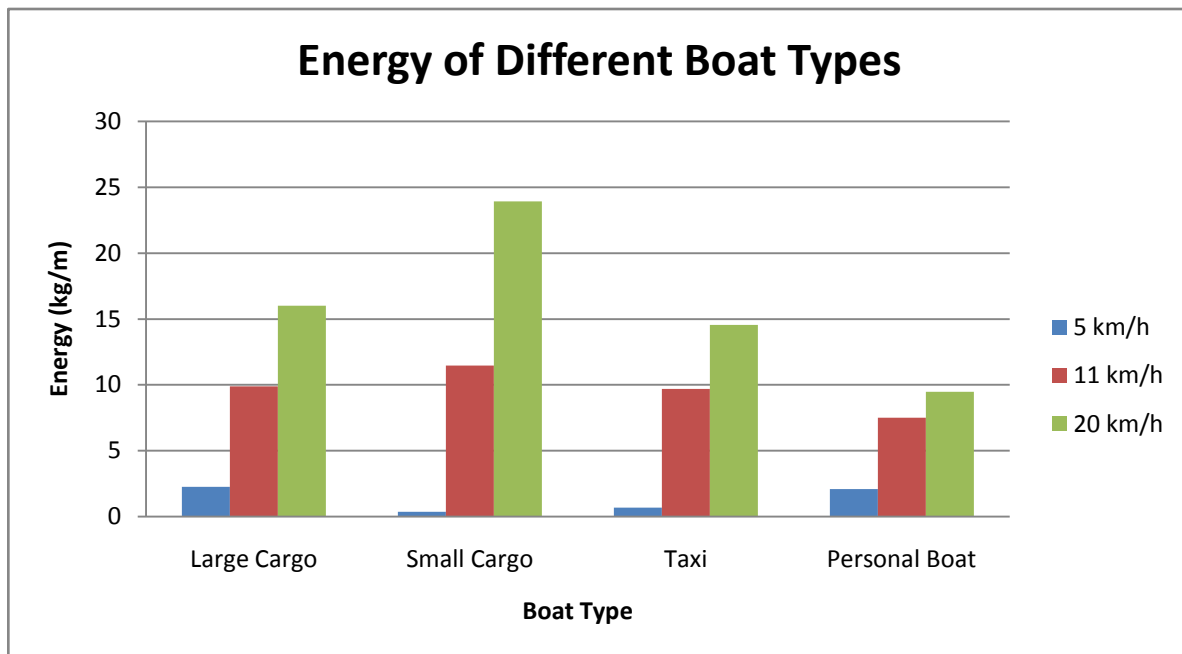


Figure 15: Energy contributed by different boat types at varying speeds

It should be clear that increased moto ondosso is the direct result of increased speed. In the aforementioned study, it was determined that only 3% of boats actually abided by the posted

¹⁰ “The Moto Ondoso Project: Assessing the Effects of Boat Traffic in the Canals of Venice” IQP Presentation, 2002.

¹¹ Comune di Venezia; "Assessorato ai Trasporti e Servizi Pubblici Commissione per lo Studio del Moto Ondoso"

¹² “The Moto Ondoso Project: Assessing the Effects of Boat Traffic in the Canals of Venice” IQP, 2002. pg 56-57

speed limits. Intuitively, more boats respecting the speed limit would drastically cut down the average speed, and therefore reduce the total moto ondosso output.

2.5 Noise pollution studies

The evolution of motorboats into the Venetian canals has led to an observable increase in the amount of noise. As the boats travel through Venice, different engines at different speeds will cause varying levels of noise. Before Venice adopted motorized boat traffic, such noise was nonexistent. Now, it is unavoidable. Undoubtedly, this new noise pollution issue is something that needs to be addressed sooner rather than later. While noise pollution seems to pale in comparison to water and wake pollution, its effects can be great. It is well documented that prolonged exposure to noise can negatively affect ones hearing to the point of hearing damage and loss. One of the less known effects of noise pollution is its effect on cardiovascular health. Exposure to moderately high levels of noise pollution during a single eight hour period, or typical work day, can cause a statistical rise in blood pressure due to a measureable increase in stress levels. Increasing vasoconstriction causes the rise in blood pressure, which is a main cause of coronary artery disease.

Measurements of noise levels produced by traveling boats were collected over a 16 hour period by ARPAV, the Agenzia Regionale Per la Prevenzione e Protezione del Veneto. The team monitored the Rio Novo over the course of the day with several microphones set up to record sound from different angles. Each observation was time-stamped such that the individual noises could closely be associated with the boat passing by at each moment. The overall goal was to determine how much noise was produced by each boat at varying speeds and angles.

Large cargo boats were the first boat type monitored during the study this volume increased marginally as speed increased, but shoots up noticeably to 84.1 decibels when making a turn.⁴ Small cargo boats follow a similar pattern, although they are significantly quieter. Travelling at 5km/h, these small merchant vessels create 68.8 decibels.¹³ In a separation from their larger cousins, these boats are actually noisier when traveling quickly straight than when making a turn. When traveling at 10km/h, twice the posted speed limit, small cargo boats output 74.2 decibels. When turning, they create only 73 decibels.¹⁴

¹³ Comune di Venezia “Analisi dell’inquinamento acustico generato dal traffico acqueo nel Rio Novo – Rio de Ca’ Foscari” 2002

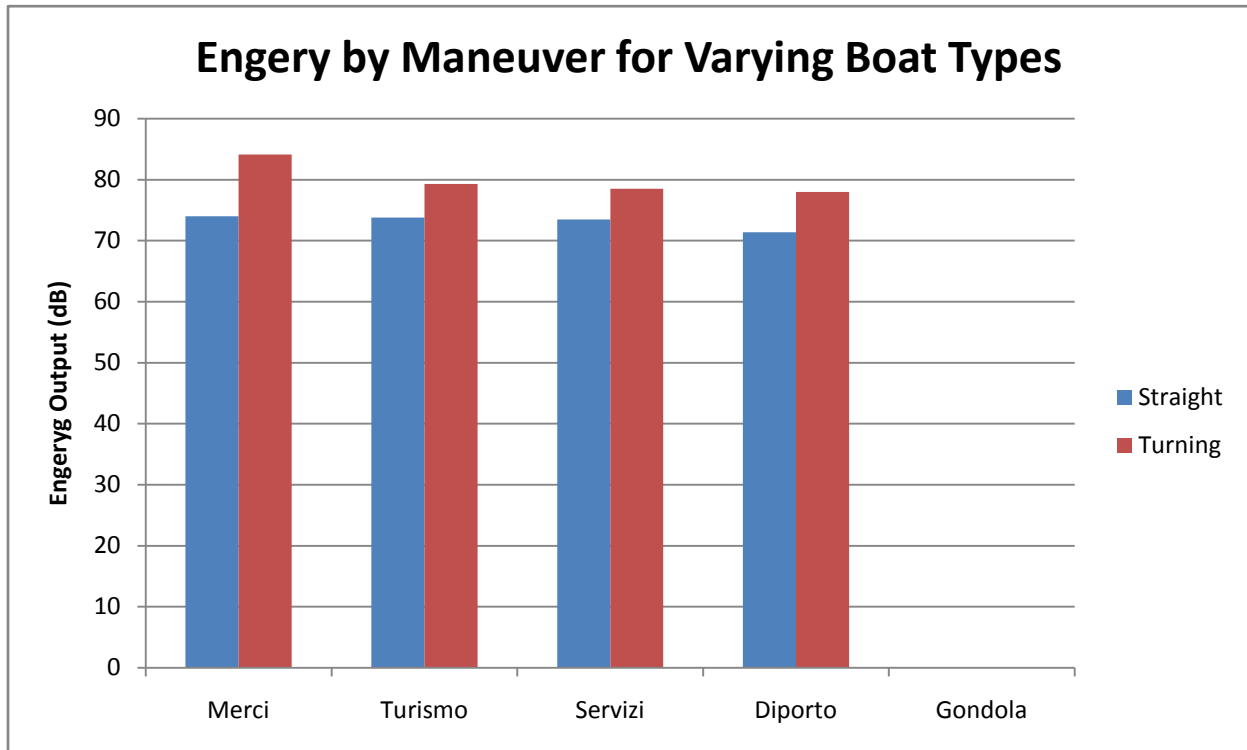


Figure 16: Energy by maneuver for varying boat types

Public transportation accounts for a significant amount of Venetian boat traffic, and as such, taxis are found everywhere. The most common taxi model outputs 73.8 decibels when traveling in a line at 5km/h. When turning, however, they output 79.3 decibels. In this way they resemble the large cargo boats, but the difference between turning and travelling straight for taxis is less significant. In fact, even when traveling at 10km/h there is only a difference of 3 decibels.¹⁵

Less prevalent in the overall scheme of Venetian traffic are personal sport boats. They cannot be ignored, though. When traveling at 5km/h, these boats output 71.4 decibels, and when they are turning these boats output 78 decibels. In keeping with the trend of other boats, they too create more noise when travelling faster.¹⁶

Of course, little can be said about noise pollution without traffic data to supplement the amount of noise outputted by each boat type. To this end, the noise pollution data collected by ARPAV was compared alongside boat traffic counts carried out by COSES over the 2006-2007 years. The quantity of boats by type counted at each station was multiplied against that particular boat type's average volume output such that a total sum of volume per station was determined.

¹⁵ Ibid.

¹⁶ Ibid

Then, these sums by station were compared to construct a noise pollution index for the canals of Venice.

2.6 Autonomous Agent Model

Traffic models are beneficial contributions to the body of city knowledge and are employed to simulate a wide variety of situations. Such models can prove invaluable in instances of emergency planning. An accurate traffic model, when affected by a simulation catastrophe, would allow city officials to determine an efficient course of action in case something similar was to happen in reality.

A more obvious use of an accurate, robust model would be to plan appropriately for times when certain canals are closed. While conducting inner canal traffic counts, it was observed that many boats would enter a canal system only to turn around out of necessity upon realizing their destination canal was blocked. A team composed of staff at the Santa Fe Institute named Redfish is working to produce a model which would accurately simulate Venetian boat traffic. The Redfish group intends to make their model dynamic and updatable such that it could redirect traffic based on such closings.

To program their model such that it most accurately simulates reality, Redfish relied entirely on COSES traffic count data. With this information, the model could intelligently account for which boats entered and exited the canal system but it could only guess as to the paths they traveled in between. In order to upgrade this representation from conjecture to informed decisions based on statistical probability

2.7 Book Chapters

In addition to counting traffic at intermediary locations and analyzing the impacts of traffic's pollution on the city, the group also created two book chapters. These two book chapters contributed to an overall book summarizing the achievements of the VPC over the past two decades. Our group contributed a chapter on the traffic of Venice and one on the impacts of traffic in Venice. These two chapters can be found in Appendix H and Appendix I.

3. Methodology

In taking our traffic counts, we sought to provide data at intersections which had not been studied. This information was used in an autonomous agent traffic model to increase its

accuracy. Using existing traffic count data alongside our own, the project group worked toward creating noise and moto ondosso pollution indices.

3.1 Area of Study

Boat traffic data is collected regularly at major intersections by COSES. No information existed for intermediate traffic intersections (Figure 17). The project group decided to implement the COSES traffic counting methodology at such intermediate intersections in order to better understand traffic flow through the inner canals. Additionally and equally important, an autonomous agent traffic model is being developed that lacked information regarding these uncounted sites. To rectify this, the intermediate sites were also chosen to increase the accuracy of the model's simulation.

The first step was determining which intermediate points were worth counting. (Figure 18) To this end, the group implemented the following criteria:

- Uncounted
- Integral to inner canal traffic flow
- Useful for making the model more intelligent

The process of station selection began by using a GIS

layer showing the major intersections that had been counted by COSES to aid in arbitrary selection of intersections which had not been counted. In the weeks that followed, the station selections evolved from arbitrary choices to educated guesses and eventually seventeen



Figure 17: COSES semiannual traffic count locations



Figure 18: Our traffic count locations

intersections were agreed upon with the project advisors. To see a map with our locations and COSES locations refer to Appendix C

Major intersections which are counted regularly by COSES were purposefully excluded so that the project group could focus specifically on intermediate canal traffic. The intent was to measure traffic in areas that had not yet been studied in order to improve the traffic model’s accuracy. An example of one such intersection is shown in



Figure 19: One of traffic count locations near the bottom of the Grand Canal

Figure 19.

3.2 Traffic Counts

Once on site, the project group decided which stations to count traffic at each morning. In teams of two, we proceeded to carry out traffic counts at two stations daily between 10am – 12pm. This time period was selected because it is representative of peak traffic hours. One person would observe the traffic and call out information while the other recorded this information on a spreadsheet. The traffic counts were informatively structured in accordance with an example datasheet (Table 1) used in official COSES counts.

Table 1: Example data sheet

From	To	Type	Time	People	Plate	Cargo (/4)
A	B	2	10:00	2	6V14593	2
A	B	6	10:00	2	LV17565	1
A	B	2	10:15	2	LV69420	2
C	A	2	10:15	2	RV11680	3

The primary concern while conducting traffic counts was accurately recording maneuvers. At each intersection, the possible paths were labeled clockwise ‘A’ through ‘D’. Each letter was used in correspondence with the direction the boat was coming from and where it was heading. Occasionally, a boat would approach the intersection only to turn around. An example of such an occurrence would be labeled ‘A’ to ‘A’.

The other vitally important observation was correctly identifying boat type. We made use of the COSES traffic field guide which categorizes the different boats into twenty-one types. A type 3, for example, is a taxi while a type 19 is a Vespa trash boat. For purposes of traffic analysis, the twenty-one boat types are consolidated into five classes: merci (merchant), turismo (tourism), servizi (services), diporto (sport), and gondola. Other considerations such as payloads, license numbers, and passenger counts were recorded but are of little significance to this report.

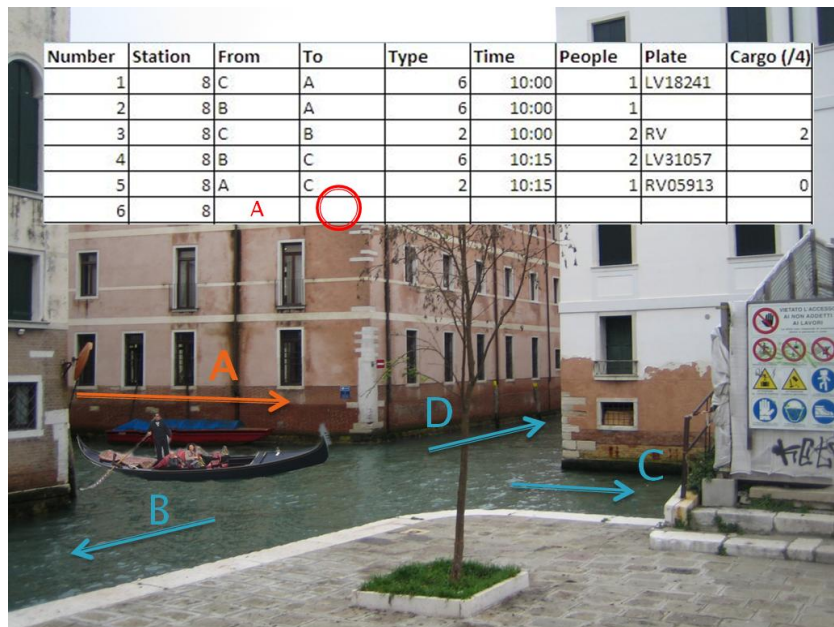


Figure 20: Methodology for traffic counts

3.2.1 Traffic Count Limitations

Traffic in Venice is ever changing. The routes of the cargo delivery boats are different every day, and depend heavily on environmental and seasonal conditions. On a rainy day, for instance, cargo boats make only the necessary deliveries and any others are postponed. In order for traffic models to take this into account, further studies must be done on how cargo routes change with inclement weather.

Additionally, the time of year and day of the week can greatly influence traffic patterns. Venice is subject to large fluctuations in its population between the high and low tourist seasons. While its economy relies heavily upon tourism, the low season causes a decrease in necessity for cargo delivery, and thus a change in traffic flow.

Our traffic counts are subject to many of the same problems. We counted each location only once, and due to our limited time, it was necessary to count every day of the week. Venetian stores have different hours every day and many are closed on Wednesdays. As a result, our data is ridden with minor fluctuations.

3.3 Moto Ondoso Index

In order to create an index of wake pollution with a corresponding gradient map it was necessary to combine traffic count data with moto ondosos data collected for each boat type. To yield the total moto ondosos created at each traffic count location we devised the following equation:

$$M = \sum_{i=1}^{21} E_i * B_i$$

Equation 1

M_i is the total moto ondosos at a station. E_i is the average energy emitted by boat type 'i' at the boat's average velocity, while B_i is the total number of boats of type 'i' counted at the station. By multiplying E_i and B_i we obtain the total moto ondosos output per boat type at each station. Then, by summing the totals for types 1 through 21, we obtain the total moto ondosos energy entered into the canal at a single station. Applying this same methodology to each station we quickly gathered totals for every counting location at which we had data.

3.3.1 The Moto Ondoso Index

One of the biggest assumptions that our project makes lies in the validity of the Moto Ondoso Index, a previous study done by WPI students. When studying their project we realized that some of their data seemed very skewed. Upon further inspection into their databases, we determined that they did not take data on nearly enough boats to make many of the assertions that they did. Mainly, the average velocity of the boats they measured were very inflated. This is not to say that they took inaccurate data, but that perhaps the locations that they chose did not best suit application to the inner canals of Venice. For instance, their project claims that the small cargo boats travel at over 20kmph on average, while the speed limit in most inner canals is only 5kmph. If this data had been measured in the lagoon or on the Grand Canal then it may be accurate. However, from our observation over the last eight weeks in Venice, we know that cargo boats do not travel this fast through the inner canals. Having no basis in discrediting their data, however, we chose to assume that their data is accurate and their engineering ethics intact. We do, however, recommend that this project be repeated, perhaps in a Mechanical Engineering MQP where students design a way to accurately measure moto ondosos and the average velocity

of boats using instruments of their own design to do the testing. Once complete, the moto ondosos values they obtain for the different boat types can be applied using our methodology, and the graphs and analyses can be made more accurate.

3.4 Noise Index

In order to create an index of noise pollution with a corresponding gradient map it was necessary to combine traffic count data with noise data collected for each boat type. The equation we formulated nearly mirrored that of our moto ondosos index with a minor difference. There is an obvious increase in noise output when boats maneuver. As boats enter a turn they tend to decelerate and when they complete a turn they accelerate back to their original speed. This acceleration causes an increase in the engine's rotations per minute which in turn creates a higher noise output. Our equation is as follows:

$$N = \sum_{i=1}^{21} (Et_i * Bt_i + Es_i * Bs_i)$$

Equation 2

N is the total noise at a station. E_{ti} is the average noise emitted by boats of type 'i' that maneuvered. B_{ti} is the total number of boats of type 'i' that turned at a given station. E_{si} is the average noise emitted by boats of type 'i' that did not turn, while B_{si} is the total number of boats of type 'i' that did not turn at a given the station. By multiplying E_{ti} and B_{ti} we obtain the total turning noise output per boat type at each station. By adding this value to the product of E_{si} and B_{si} , the total noise of boats that went straight, we obtain the total turning noise output per boat type at each station. Finally, by summing the totals for types 1 through 21, we obtain the total noise emitted at a single station. Applying this same methodology to each station we quickly gathered totals for every counting location at which we had data.

3.4.1 Noise Pollution Study Limitations

The noise pollution data on which our index values relied is also subject to a few inaccuracies. When ARPAV collected their data, it seems that many assumptions were made about engine types, one being that all boats of a given type have the same engine and that these engines are roughly the same age. Intuitively, an older engine does not run as efficiently as a new one, and as a result increased losses through vibration increases the noise output of an

engine. Assuming that all engines are roughly the same age and have similar noise output is incorrect. Additionally, the data was not related to payload. The amount of cargo in a boat increases the force that the engine needs to exert in order to achieve certain acceleration. In order to achieve this increased force, the engine must run at higher revolutions per minute and therefore create more noise. This error, however, is easily remedied with further study. Since traffic counts currently take data on the payload of each passing boat, knowledge of how engine noise increases with payload can be easily applied.

3.5 Spatial Extension

Traffic counts have not been conducted at every possible intersection throughout the canal system. In order to extrapolate data between counting locations, linearity was assumed. While not an entirely accurate representation of the uncounted areas, this method of spatial extension provides a workable estimation.

3.6 Longitudinal Analysis

Over the past seven years COSES has been conducting traffic counts at twenty one stations semiannually. Trends of the traffic counts have yet to be studied. In order to create such trends, station count data was compiled and queries were run. In doing so, we included the number of boats at each station by type and the total number of boats by type for each year. This new set of data was then put into a spreadsheet to graphically represent the trends. A best fit line was applied to each set of data and an equation was obtained. This equation can be used to extrapolate the traffic data for several years to come.

4. Results and Analysis

The following chapter presents the data collected by the project team between October and December, 2007.

4.1 Traffic Counts and Turning Movements at Intermediate Intersections

Figure 21 below represents the traffic counts carried out by the project team at

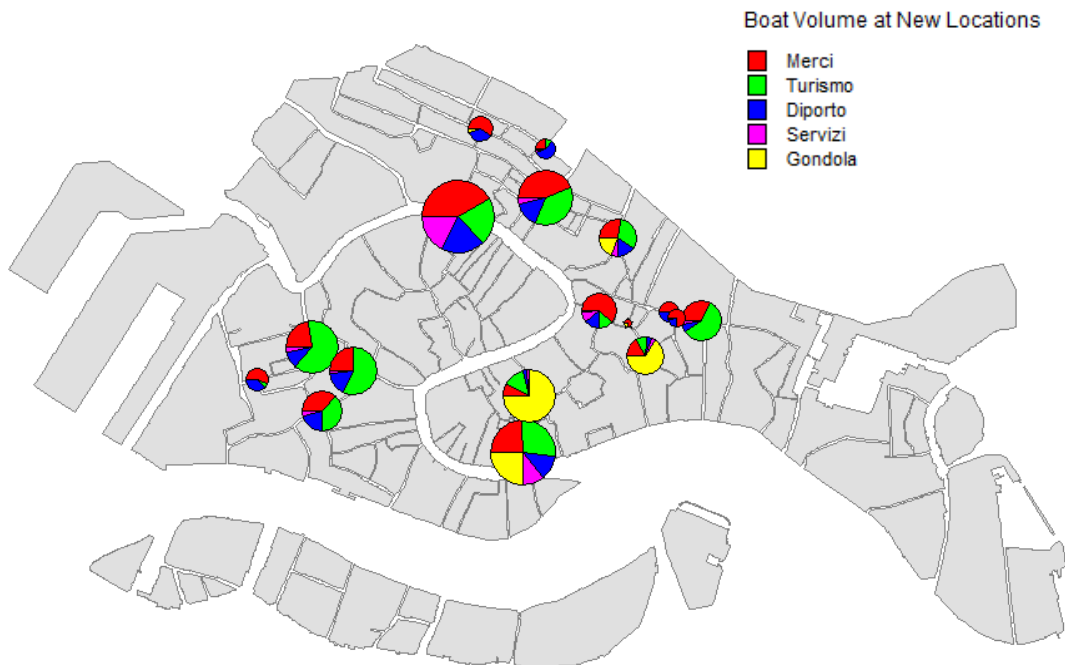


Figure 21: Boat volume at our traffic counts broken down by boat type

intermediate locations. Each pie graph displays percentages of traffic by boat class. The volume of the circle is proportional to the number of boats counted at each location. Generally, the traffic was dominated by *turismo* and *merci* boats, but there are some instances where other classes are more prevalent. One example is the *gondole* which represent a tiny portion of overall boat traffic in Venice (refer to Figure 24) In and around *la piazza san Marco* where tourists frequent, *gondole* are clearly the leading contributor to boat traffic. (To see map of COSES locations refer to Appendix D)

4.2 Moto Ondoso Index and Major Contributing Boat Types

Spatially extended traffic data was applied as described in 3.3 of the methodology chapter to create index values for each canal segment. A sampling of these index values are shown in the following table.

Table 2: Moto Ondoso index values

Station Number	Total Moto Ondoso
1	21664
2	19759
4	11800
5	12166
6	30197
7	34030
8	17486
9	13892
10	20535

Each of these values (and others found in Appendix E) was used to create the color-coded gradient map shown below in Figure 22.

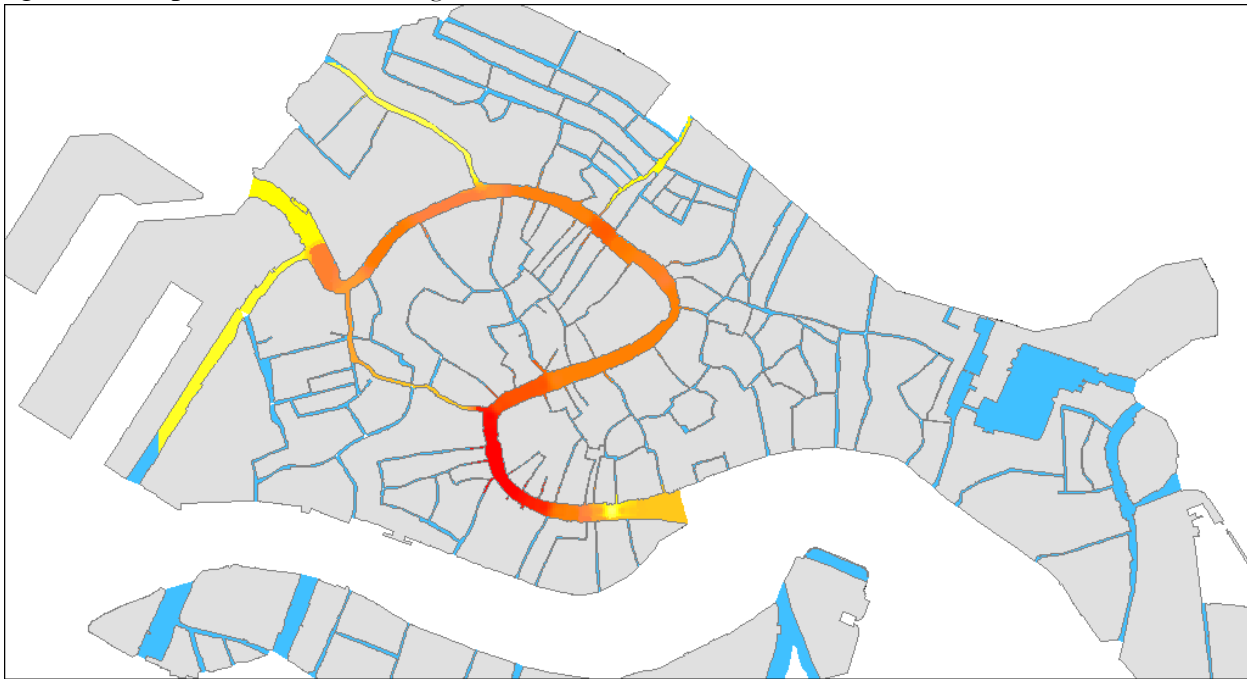


Figure 22: Moto ondosos gradient map

Intuitively, a higher level of moto ondosso is observed in the Grand Canal due in large part to the high volume of traffic. Despite this, it is incorrect to assume that the volume of traffic is the only factor in determining total moto ondosso. As shown in Figure 24 and Figure 23, the percentage that a single boat class contributes to total traffic is not equal to the percent of the total moto

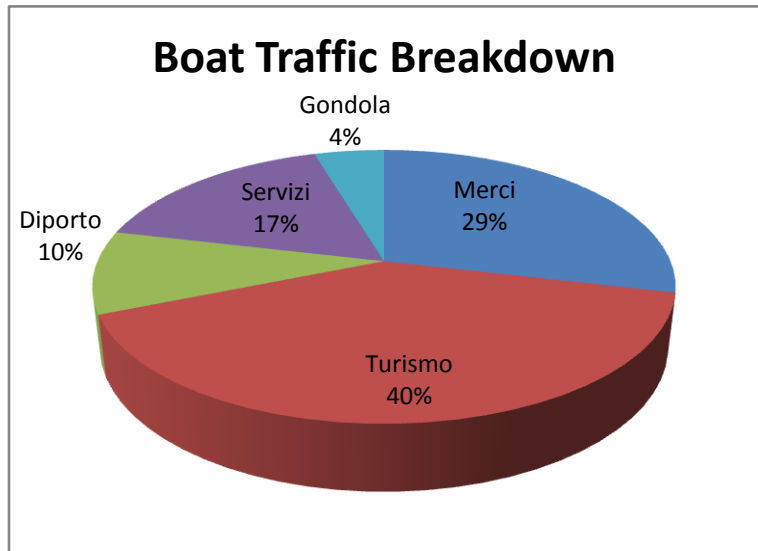


Figure 24: Moto ondosso contribution by class

ondosso for which they are responsible. This is especially evident in *gondole* which account for 4% of the traffic in Venice (as of August 2007). Their lack of motor and subsequent low speed allows them to move through the water creating virtually no turbulence and accounting for 0% of the total moto ondosso in Venice.

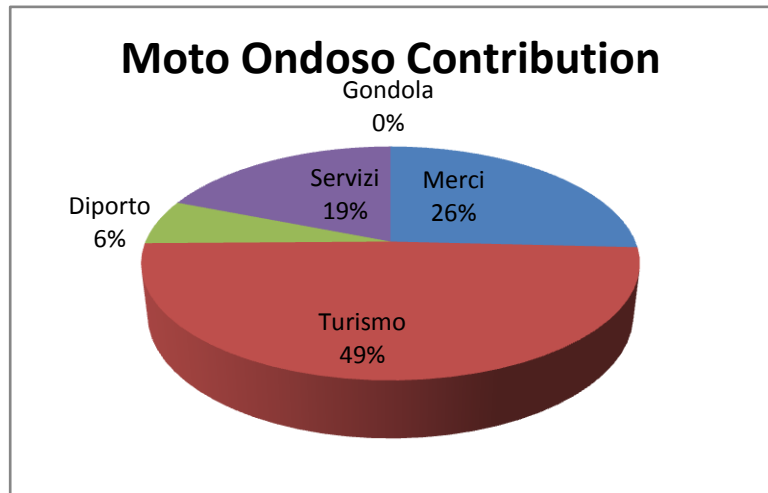


Figure 23: Percentage that each class contribute to total volume

Conversely, the turismo boats account for only 40% of the total traffic while they contribute nearly half of the total moto ondosso in Venice. This gaping disproportion is caused mainly by the taxi boats' high moto ondosso output. At their average speed, a taxi boat with medium payload outputs 14.85 kg-m of moto ondosso¹⁷.

While taxi boats are one of the main contributors to moto ondosso, their contribution can be easily mitigated through speed limit enforcement. Driving at the recommended speed limit of 5 kmph would reduce the taxis' moto ondosso output by 95% to 0.69 kg-m¹⁸. Likewise, if the

¹⁷“The Moto Ondosso Project: Assessing the Effects of Boat Traffic in the Canals of Venice” IQP, 2002. pg 49

¹⁸ “The Moto Ondosso Project: Assessing the Effects of Boat Traffic in the Canals of Venice” IQP, 2002. pg 49

small cargo boats (type 2) travelled at 5kmph they would reduce their moto ondosu output by 98.5%. Similar patterns can be seen in Figure 15

4.3 Noise Pollution Index and Major Contributing Boat Types

Spatially extended traffic data was applied as described in Section 2.5 to create noise index values for each canal segment (refer to Appendix F). A sampling of these index values are shown in Table 3.

Table 3: Noise index values

Station Number	Total Noise
1	112610
2	116060
4	83165
5	85682
6	19447
7	175110
8	120910
9	80876
10	100580

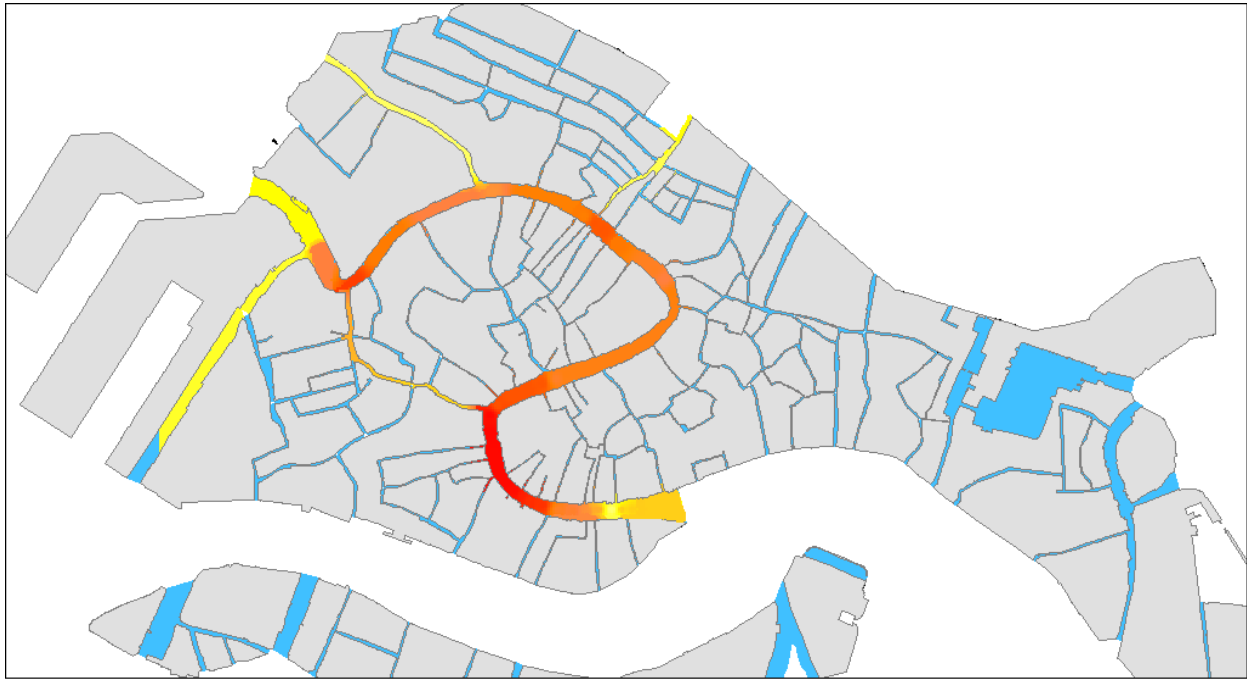


Figure 25: Noise pollution gradient map

Index values were calculated for each traffic station and then a color coded index was created based on them.

Areas of high noise pollution are indicated by red and areas of lesser noise pollution are indicated decreasingly between red and yellow. The areas of highest noise pollution are located along the Grand Canal and throughout parts of the Rio Novo as well as the ring connecting canals. The main contributor to high noise levels is a high level of traffic, but the assumption that noise level is entirely dependent on traffic volume is erroneous.

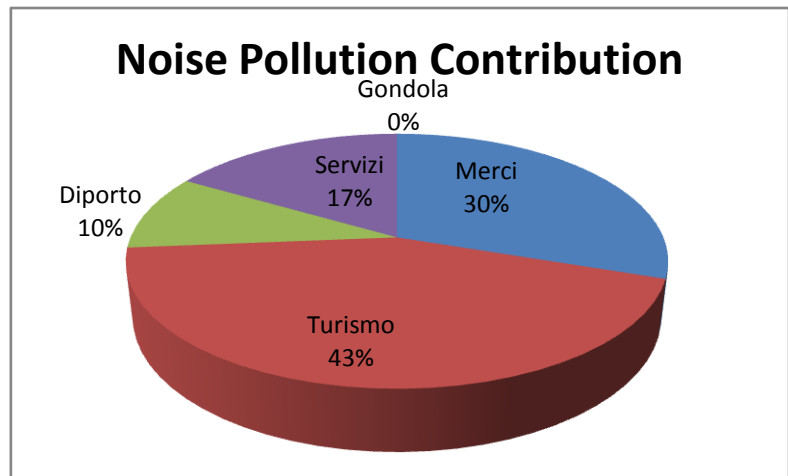


Figure 27: Noise pollution by boat class

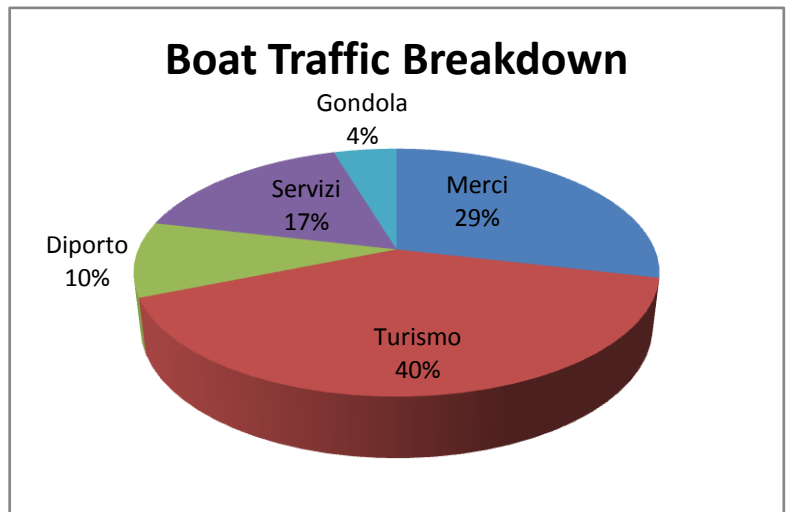


Figure 26: Percentage that each class contribute to total volume

The different boat classes each produce, on average, a different amount of noise pollution per boat. Twenty cargo boats, twenty *gondole*, or twenty taxis would all affect an overall noise total in different ways. The percentage of noise pollution by boat type was calculated and is displayed in Figure 27. One striking example is the gondola class which accounts for 4% of the total traffic population but contributes 0% to overall noise. This difference is accounted for by the *turismo* boats which output 43% of the overall volume while making up only 40% of overall traffic.

Another important consideration in evaluating overall noise output is that boats output more noise while maneuvering. Therefore, intersections where boats are more apt to turn are noisier (refer to Appendix G). Figure 16 shows a comparison between the average noise output of each class when turning and traveling straight. In every case, more noise is made when turning than when turning straight. The only exception is the gondola group which does not output any noise whatsoever.

5. Conclusions and Recommendations

5.1 Traffic

Traffic studies are the foundation of meaningful traffic analysis. They allow city officials to make educated decisions about traffic regulation. With continued traffic studies, the body of traffic information increases. We therefore recommend further study to facilitate more informed decision making.

Traffic models are employed primarily for emergency planning and traffic efficiency. Current models are based on existing traffic to run an accurate simulation. Thus, an increase in traffic counts could only lead to a more intelligent model. As an example, our traffic counts were able to increase modeling accuracy by up to 333%. In Figure 28 below, you can see two previously counted intersections indicated by red dots. The numbers of boats counted at these points are shown. Note that there is a difference of 240 boats between the two points. A model might assume equal distribution of the difference across the four possible intersections where boats can divert. With the addition of our data, however, the model gains a more accurate understanding of how boats travel at these locations. We recommend frequent traffic counts at more locations in order to increase model precision.

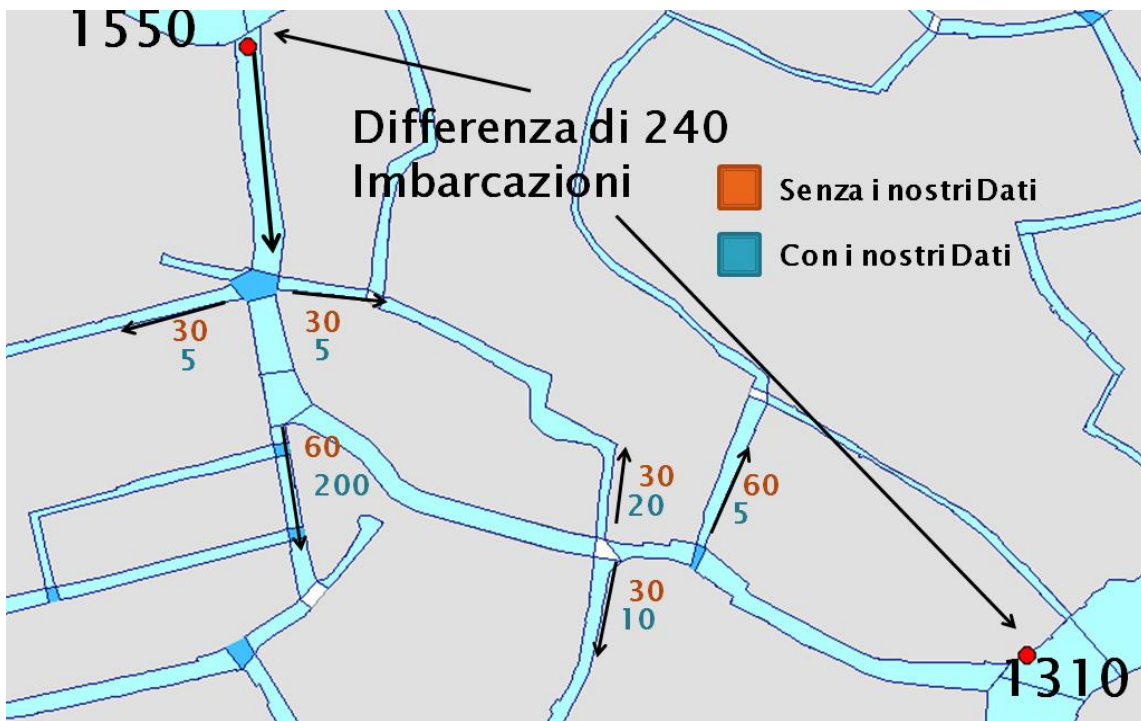


Figure 28: Map shows increased accuracy with the addition of our data

The methodology for traffic counting could stand to be improved as well. One such improvement would be adapting the technique to consider weather. Traffic patterns are dramatically affected by inclement weather. Understanding traffic trends as a function of weather patterns is valuable. In addition, traffic patterns are subject to change depending on the day of the week. Therefore we recommend adapting the methodology to account for this.

5.2 Moto Ondoso

It is clear that moto ondosso would not exist in the absence of motorboats. While many people subscribe to the line of thinking that removing motorboats from the canals of Venice would remove this problem, it is clear that doing so is a threat to the efficiency of goods delivery, a convenience that Venice's economy relies upon heavily. It is an altogether unrealistic ideal which could better be served by regulation.

Moto ondosso output exponentially increases as speed increases. With this in mind, there are many traffic regulations that can lessen the effects of wake pollution; speed limit enforcement being one of the most obvious. As shown above, boats traveling at the posted speed limits produce significantly less wake pollution than at their average speed. While it may not be feasible to post police boats throughout the canal system, we recommend stricter enforcement. This can be achieved in part by increasing speeding fines. Additionally, we believe it would be helpful to raise public awareness in hopes that people better understand the degree to which they can prevent excess wake pollution.

5.3 Noise Pollution

Not unlike water pollution, noise pollution in Venice is a direct result of motorized traffic. Venice had previously been known as the “most serene republic” and was widely recognized for its tranquility. Now, Venice shares a similarity with other major cities in that it is subject to the sounds of modern traffic. Noise pollution can also be lessened through traffic reduction. The problem persists, though, that cutting back traffic entirely is an impractical solution.

A possible way to address noise pollution is to impose time restrictions by class in specific areas. This can be done by considering the time of day, residential population, and canal function. For example, it may be unnecessary for taxis to parade through a highly residential area during siesta if an alternate route existed. Conversely, it would not make sense to impose the same restriction on *gondole*.

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Appendix A: Boat Type Field Guide

TIPOLOGIA DELLE IMBARCAZIONI

TIPO 1 – UNITA' MERCI GRANDE

TIPOLOGIA	TARGHE	NOTE
Mototopo, topo grande, motobarca, barcone, topa entrobordo, cofano grande, patana grande, sampierota grande).	<i>Più frequente:</i> 6V: 1nnn, 3nnn, 4nnn, 13nnn, 14nnn, 23nnn, 30nnn, 4nnnn; V: da 10nnn a 13nnn e 0nnnA; <i>più raro:</i> LV; VE: da 2nnn a 8nnn.	In caso di rilevazione parziale della targa, riportare qualche altro elemento utile (nome, scritte laterali), nelle note specificare la presenza di cabina (cisterna, cella frigorifera, gru, altro).



TIPO 2 – UNITA' MERCI PICCOLA

TIPOLOGIA	TARGHE	NOTE
Sampierota, topetta fuoribordo, patanella, barchino, cofanetto, zatterino.	<i>Più frequente:</i> 6V: 1nnn, 3nnn, 4nnn, 13nnn, 14nnn, 23nnn, 30nnn, 4nnnn; V: da 10nnn a 13nnn e 0nnnA; <i>più raro:</i> LV; VE: da 2nnn a 8nnn.	In caso di rilevazione parziale della targa, riportare qualche altro elemento utile (nome, scritte laterali), nelle note specificare la presenza di cabina (cisterna, cella frigorifera, gru, altro).



TIPO 3 – MOTOSCAFO TIPO TAXI

TIPOLOGIA	TARGHE	NOTE
Lance in legno o vetroresina senza indicazioni di appartenenza a enti pubblici o privati (mezzi in servizio pubblico, regolari – con striscia gialla - o abusivi).	<i>Più frequente:</i> VE: da 2nnn a 8nnn; <i>più raro:</i> 6V: 13nnn, 14nnn, 23nnn, 30nnn; V: da 10nnn a 13nnn e 00nnA.	Rilevare sempre la targa ed eventualmente il nome, sempre il nome se non si riesce a rilevare la targa, indicando se esiste la striscia gialla.



TIPO 4 – LANCIONE GRANTURISMO

TIPOLOGIA	TARGHE	NOTE
Grossa lancia con posto di comando centrale, spesso scoperto, e posti per passeggeri a prua e a poppa, spesso coperti, (mezzi in servizio pubblico, noleggio regolari – con triangolo giallo – o abusivi, linea – con tabelle; mezzi in servizio privato per alberghi – CIGA – e attività turistiche – vetrerie di Murano).	<i>Più frequente:</i> VE: da 2nnn a 8nnn <i>più raro:</i> 6V: 13nnn, 14nnn, 23nnn, 30nnn; V: da 10nnn a 13nnn e 00nnA.	Rilevare sempre la targa ed eventualmente il nome, sempre il nome se non si riesce a rilevare la targa, indicando se esiste la striscia gialla o se c'è indicazione di linea o il nome dell'attività turistica proprietaria (CIGA, etc.).



TIPO 5 – NATANTE TURISTICO (2 PIANI)

TIPOLOGIA	TARGHE	NOTE
Motoscafo per comitive turistiche, completamente chiuso o con ponte superiore scoperto.	<i>Più frequente:</i> VE: da 2nnn a 8nnn; 3VE nnn; CI nnn; 2CI nnn; <i>Più raro:</i> nXXnnn; 6V 000n, 13nnn, 14nnn, 23nnn, 30nnn.	Rilevare sempre la targa e anche il nome ove possibile, almeno il nome se non si riesce a rilevare la targa.



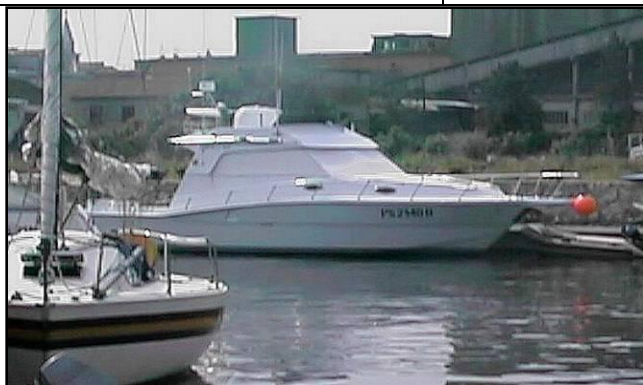
TIPO 6 – BARCA DA DIPORTO SENZA CABINA

TIPOLOGIA	TARGHE	NOTE
Barchino, cacciapesca, cofano, zatterino, gommone, unità da diporto a motore adatte ad escursioni giornaliere (marche di costruzione più frequenti: Boston Whaler, Brube, Dese, Gobbi, Studio 5).	<i>Più frequente:</i> LV; <i>più raro:</i> V: da 10nnn a 13nnn e 00nnA; VE: da 2nnn a 8nnn, nnnn D, nnn ND; N: 1nnnn VE, nnnn TV o PD o altra provincia; nVE: nnn, nnn D; CI: nnn D; nCI: nnn D; ancora più raro: nXXnnnnD.	Indicare se non ha targa.



TIPO 7 – BARCA DA DIPORTO CON CABINA

TIPOLOGIA	TARGHE	NOTE
Unità da diporto a motore ad 1 o più ponti con cabina adatte alla permanenza in mare per più giorni.	<p><i>Più frequente:</i> V: da 10nnn a 13nnn e 00nnA; VE: da 2nnn a 8nnn, nnnn D, nnn ND; <i>più raro:</i> N: 1nnnn VE, nnnn TV o PD o altra provincia; nVE: nnn, nnn D CI: nnn D; nCI: nnn D; ancora più raro: LV; nXXnnnnD.</p>	Indicare se non ha targa e l'eventuale nome con compartimento marittimo di registrazione (specchio di poppa) soprattutto se di altra nazionalità.



TIPO 8 – BARCA DA DIPORTO A VELA

TIPOLOGIA	TARGHE	NOTE
Unità da diporto a vela di qualsiasi dimensione.	<p><i>Più frequente:</i> V: da 10nnn a 13nnn e 00nnA; VE: da 2nnn a 8nnn, nnnn D, nnn ND;</p>	Indicare se non ha targa, se naviga a vela e l'eventuale nome con compartimento marittimo di registrazione (specchio di poppa) o

	<p><i>più raro</i>: LV; N: 1nnnn VE, nnnn TV o PD o altra provincia; nVE: nnn, nnn D CI: nnn D; nCI: nnn D; ancora più raro: nXXnnnnD.</p>	<p>sigle sulla vela soprattutto se di altra nazionalità.</p>
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TIPO 9 – UNITA' A REMI

TIPOLOGIA	TARGHE	NOTE
Barca tipica veneziana (gondola, sandolo, mascaretta, etc.) più canoa, kayak, jole, veneta.	Senza targa.	Specificare se appartiene a gruppi sportivi organizzati (scritte laterali).



TIPO 10 – ALILAGUNA

TIPOLOGIA	TARGHE	NOTE
Grossa lancia con posto di comando centrale, spesso scoperto, e posti per passeggeri a prua e a poppa, spesso coperti.	<i>Più frequente:</i> VE: da 2nnn a 8nnn <i>più raro:</i> 6V: 13nnn, 14nnn, 23nnn, 30nnn; V: da 10nnn a 13nnn e 00nnA.	Rilevare sempre la targa ed eventualmente il nome, sempre il nome se non si riesce a rilevare la targa.



TIPO 11 – NAVI E NAVETTE

TIPOLOGIA	TARGHE	NOTE
Nave marittima in metallo di grossa e media stazza.	Senza targa, solo nome e compartimento marittimo.	Rilevare il nome e compartimento marittimo, specificando se nave da passeggeri (nave traghetto, catamarano, nave da crociera, aliscafo, etc.) o da carico (ro-ro, cisterna, rinfuse secche, etc.).



TIPO 12 – PESCHERECCI E RIMORCHIATORI

TIPOLOGIA	TARGHE	NOTE
Piccole navi da pesca e navi per rimorchio o spinta in navigazione isolata.	<p>Pescherecci più frequente: VE nnnn, nVEnnnn, CI nnn, nCIInnn</p> <p>Rimorchiatori più frequente: senza targa, solo nome; <i>più raro:</i> VE nnnn, CI nnnn, 6V nnnn.</p>	Rilevare sempre la targa e anche il nome ove possibile, almeno il nome se non si riesce a rilevare la targa.



TIPO 13 – CHIATTE E ZATTERE

TIPOLOGIA	TARGHE	NOTE
Natante fluviale o lagunare a basso profilo, eventualmente con gru e natante di metallo rettangolare, solitamente trainato da altra imbarcazione.	<p>Pescherecci più frequente: VE nnnn, nVEnnnn, CI nnn, nCIInnn</p> <p>Rimorchiatori più frequente: senza targa, solo nome; <i>più raro:</i> VE nnnn, CI nnnn, 6V nnnn.</p>	Rilevare sempre la targa e anche il nome ove possibile, almeno il nome se non si riesce a rilevare la targa.



TIPO 14 – MOTONAVE E FERRYBOAT ACTV

TIPOLOGIA	TARGHE	NOTE
Motonave o nave traghetto di linea.	Sempre VE nnn o nnnn.	rilevare il nome in alternativa alla targa.



TIPO 15 – VAPORETTI ACTV

TIPOLOGIA	TARGHE	NOTE
Vaporetto ACTV.	Sempre VE nnn o nnnn.	Rilevare il nome o il numero in alternativa alla targa.



TIPO 16 – MOTOSCAFI ACTV

TIPOLOGIA	TARGHE	NOTE
Motoscafo ACTV.	Sempre VE nnnn.	Rilevare il nome o il numero in alternativa alla targa.



TIPO 21 – PILOTINA BLU ACTV

TIPOLOGIA	TARGHE	NOTE
Motoscafo ACTV.	Sempre VE nnnn.	Rilevare il nome o il numero in alternativa alla targa.



TIPO 17 – ALTRA UNITA' GRANDE Lunghezza > 10 m

TIPOLOGIA	TARGHE	NOTE
Tipo merci grande o in caso di difficoltà nella classificazione.	Qualsiasi.	In caso di rilevazione parziale della targa, riportare qualche altro elemento utile (nome, scritte laterali), nelle note specificare la presenza di cabina, cisterna, cella frigorifera, gru, altro).

TIPO 18 – ALTRA UNITA' PICCOLA Lunghezza < 10 m

TIPOLOGIA	TARGHE	NOTE
Tipo merci piccola o in caso di difficoltà nella classificazione.	Qualsiasi.	In caso di rilevazione parziale della targa, riportare qualche altro elemento utile (nome, scritte laterali), nelle note specificare la presenza di cabina, cisterna, cella frigorifera, gru, altro).

TIPO 19 – VESTA TRASPORTO RIFIUTI URBANI

TIPOLOGIA	TARGHE	NOTE
Natante lagunare di colore verde dotato eventualmente di gru.	Qualsiasi.	Rilevare il nome o il numero in alternativa alla targa



TIPO 20 – GONDOLA

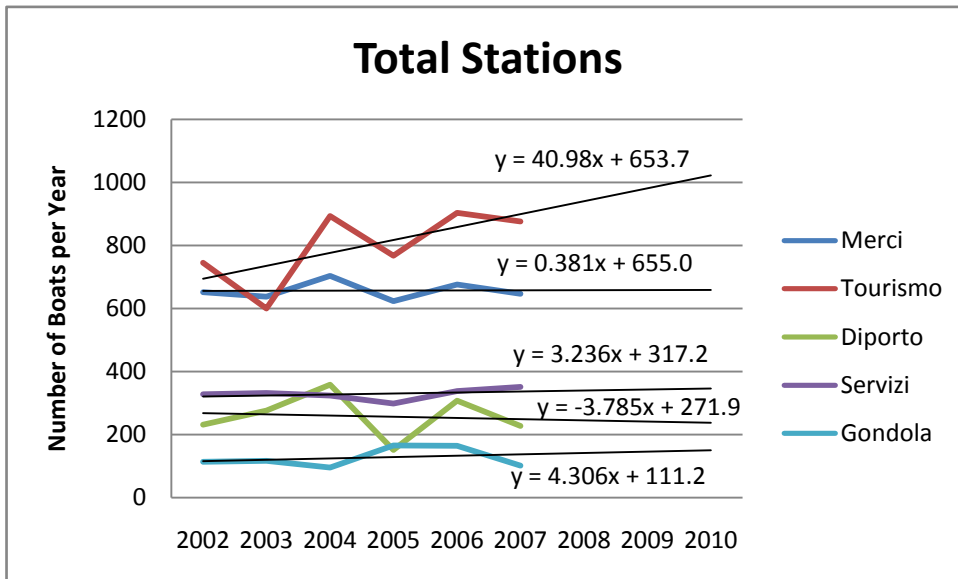
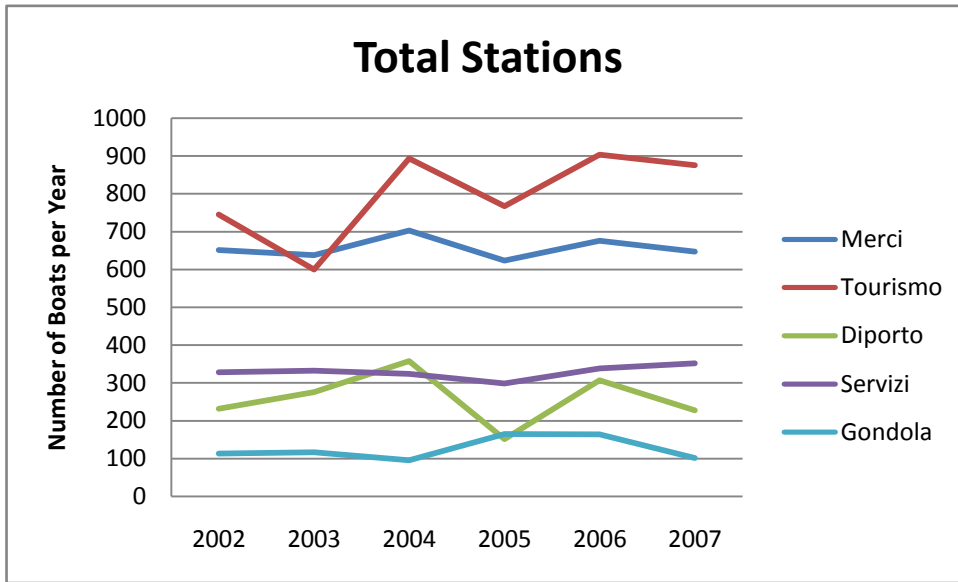
TIPOLOGIA	TARGHE	NOTE
Barca tipica veneziana (gondola)	Senza targa.	

ESEMPI DI TARGHE

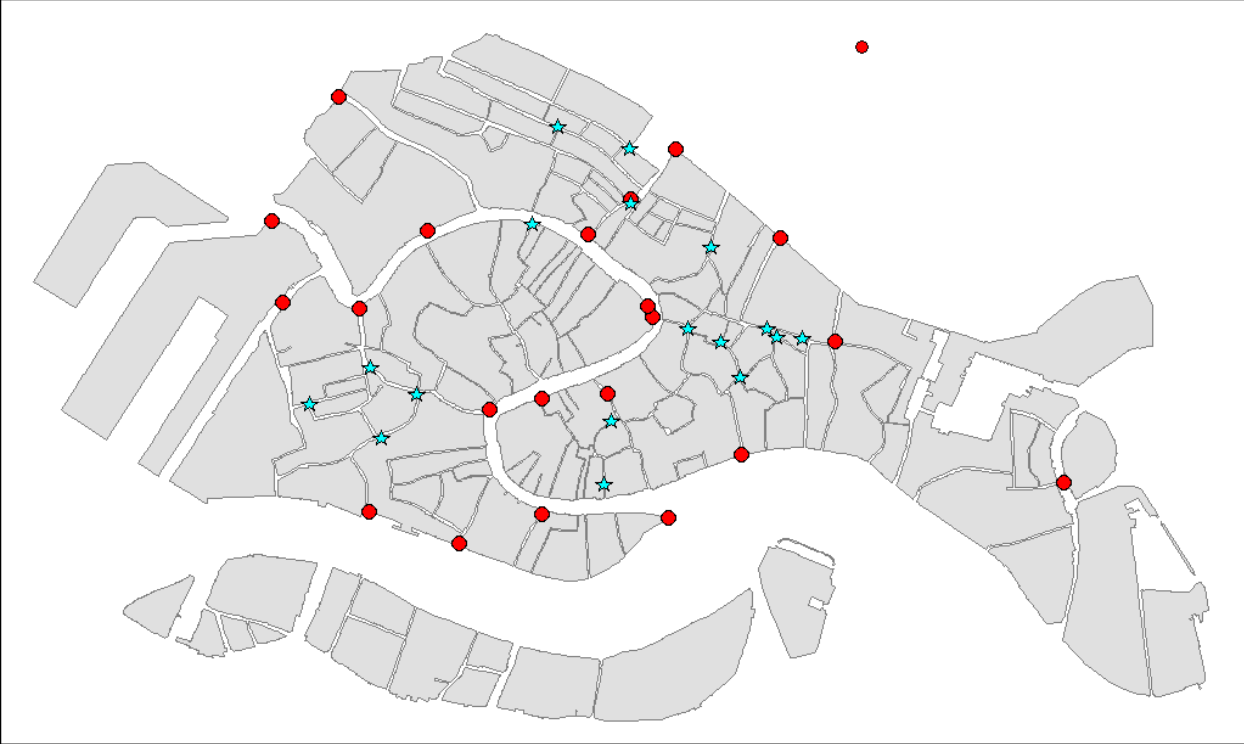




Appendix B: Longitudinal Analysis Graphs

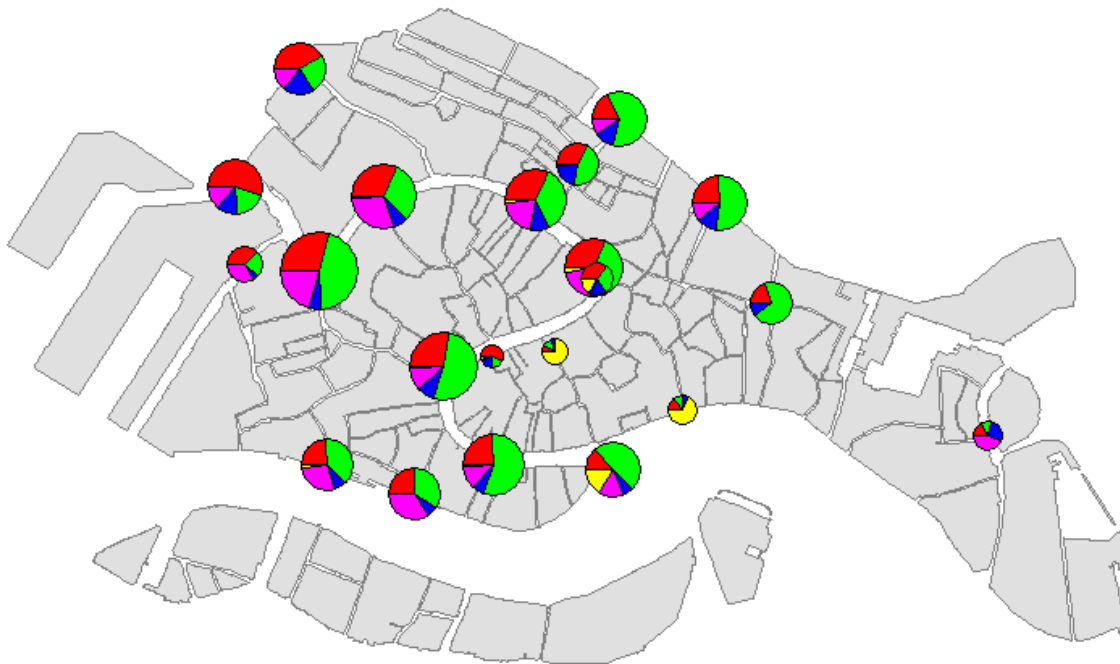
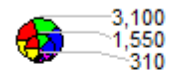


Appendix C: WPI Station Count Locations



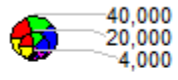
Appendix D: Total Volume by Boat Type

April 2007 Boat Types by Category

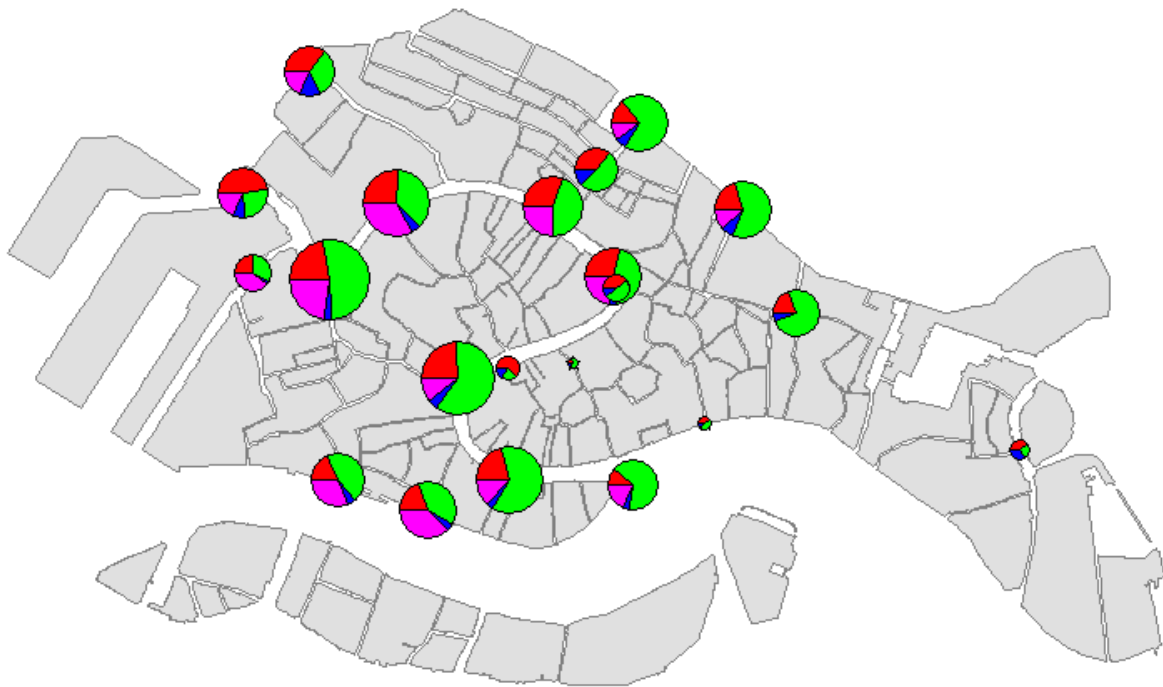


Appendix E: Moto Ondoso by Boat Class

Moto Ondoso by Boat Category

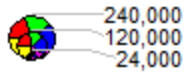


- Moto_Ondoso_Merci
- Moto_Ondoso_Turismo
- Moto_Ondoso_Diporto
- Moto_Ondoso_Servizi
- Moto_Ondoso_Gondola

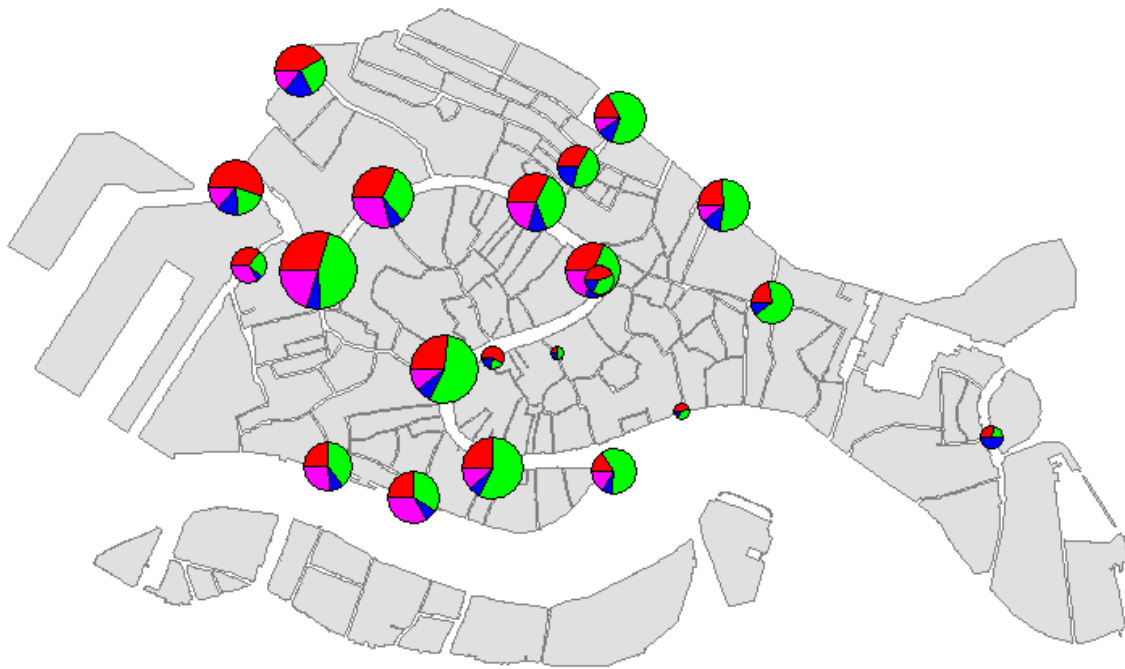


Appendix F: Noise by Boat Type

Noise Emitted by Boat Type

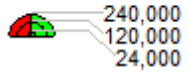


- Gondola
- Servizi
- Diporto
- Turismo
- Merci

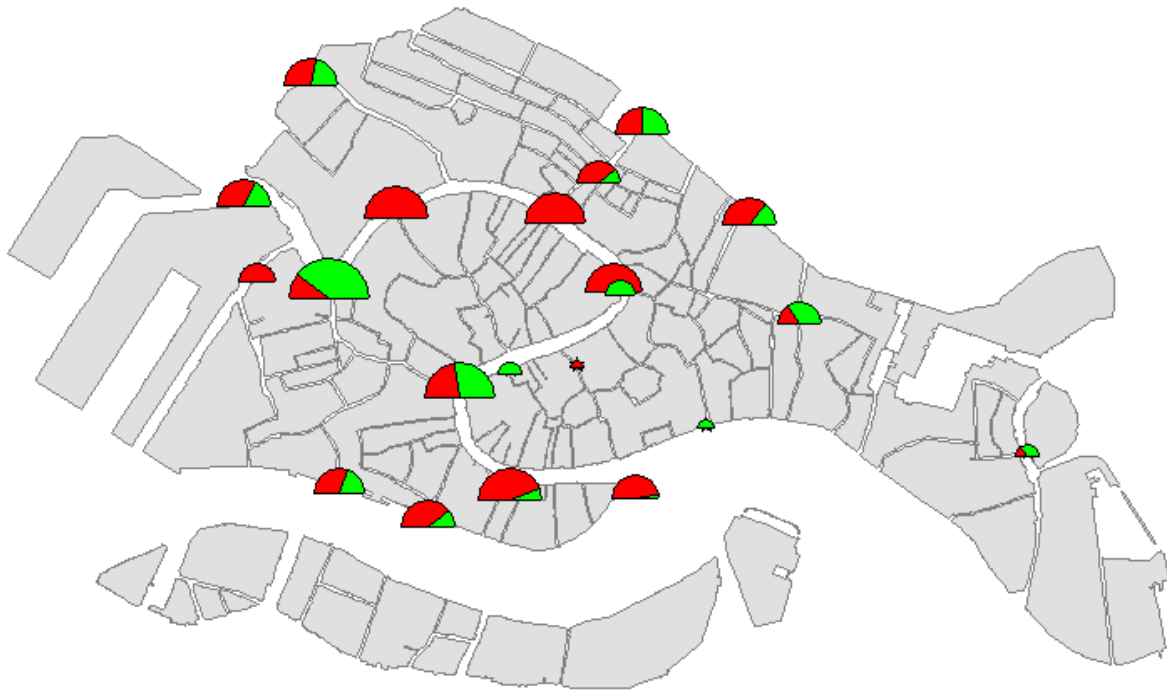


Appendix G: Turning Percentages

Turning or Straight



■ Straight
■ Turn



Appendix H: Venetian Traffic

The Venetian system of urban transport is always in a state of contradiction between the radical differences of the network to an equally radical separation of its functions: the network of viable water and the network of viable land. The first is almost exclusively reserved for transportation of people, as well as goods shipments and trash pickup. The second comprises the majority of land movement of people and all of the final distribution of the goods.



The prevailing component of water traffic regulates the commercial activity of the transportation of people and goods.

This double infrastructure for transportation is universally recognized as the optimal way of looking at the separation of the flow of transportation and therefore, by definition, the quality of urban life. This is comparable to the situation of a modern city.²

Nevertheless, the system of urban water transportation in Venice has reached, over the past few years, a crisis point, where pressing issues have been brought to the forefront. In order to be successful, rigorous attention must be paid to the planning of traffic and other components, such as the constant flow of movement.

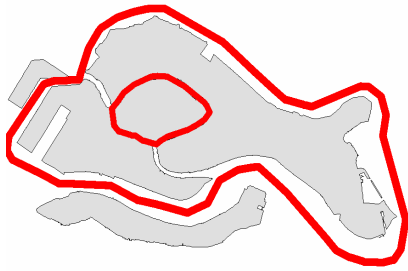
The structure of the transportation network

Observed from the point of view of transportation, the canals in Venice present the typical network of a historical center from the middle ages, characterized by the streets' irregular trends and their sectional variability. The peculiarity consists in the fact that, instead of

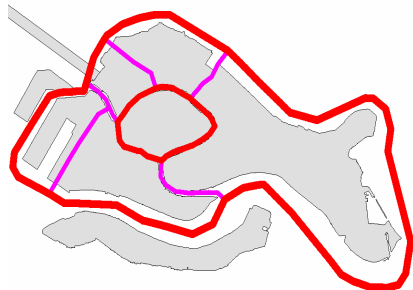
converging in numerous public squares, the network of canals flow the water away along an axial course.

The presence of the lagoon, which encircles the city with wide and deep navigation channels, acts as a system of travel around Venice. The wide section of the Grand Canal and some of the main inner city canals connect the two systems of the inner and outer city. It certainly has had some minor difficulties with adapting to modern motorized traffic, particularly regarding the old

city of dry land: with the exception of some limited branches, the entire network is accessible by motorboat.

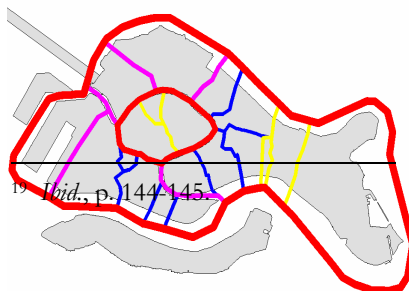


The most important traffic arteries within and surrounding Venice can be represented by two concentric rings¹⁹ (red rings in figure on left). The outer ring includes the *Canale delle Fondamente Nuove*, *Colombola*, *Tronchetto*, *Giudecca*, *Bacino di S.Marco*, and the *Canale delle Navi*. The inner ring is made up of the central part of the Grand Canal and the entirety of the *Rio Nuovo*.



The next level of arteries includes the *Rio de Noal*,

Canale di Cannaregio, the northernmost and southernmost tails of the Grand Canal and the *Scomenzera*. These canals connect the inner ring with the outer ring (purple). These connecting canals coupled with the rings themselves account for the majority of traffic in Venice if for no other reason than they are frequented heavily by taxis and vaporetto. Public transportation boats from the ACTV (*Azienda del Consorzio Trasporti*



¹⁹ *Ibid.*, p. 144-145.

Venezia) travel all of these canals as well, except the *Rio de Noal*.

Moving past those two main groups of passageways, there are two more types of arteries that play a vital role in the flow of traffic in Venice. These are the secondary arteries (blue in the side diagram) and the bypass canals (yellow). The secondary arteries include the *Rio de S. Sebastian*, *Carmini*, *Briati*, and *Tre Ponti*, connecting the *Canale della Giudecca* to the *Rio Novo*. The blue canals also include the two parallel canals in Dorsoduro that allow travel between the *Canale della Giudecca* and the *Canal Grande* (*Rio de San Trovaso* and *de San Vio*), and the two parallel canals that connect outer and inner ring across the borough of San Marco (*Rio de S. Moisè* and *Rio de la Canonica*, *S.Zulian*, *de la Fava* and *Rio del Fontego dei Tedeschi*). The list of secondary arteries is completed by two canals that connect inner and outer rings to the north and East, namely the *Rio dei Santi Apostoli* and the *Rio de Santa Marina* (which actually connects the inner ring to one of the bypass canals described below).

The final major elements of the water traffic network in Venice are canals that bypass parts of the network and create shortcuts (yellow) between two parts of the inner and outer rings. For instance, the *Rio de San Polo* and the connecting *Rio Marin* e *Rio de San Zandegolà* together create a “Y-shaped” bypass that cuts right through the heart of the inner ring inside the boroughs of S.Polo and Santa Croce. Similarly, the *Rio de Santa Giustina* and the *Rio dei Greci* and *Sant’Antonin* form an inverted Y that connects two parts of the outer ring in the Castello region, as does the *Rio de l’Arsenale* a little farther East.

Now go and consider the problems created by the indiscriminate use of motorized traffic, first the issue of moto ondosio. Canal waves created by passing boats have the power to damage buildings and surrounding structures and they occasionally do. Moreover, the circulation outline changes continuously, as a consequence of the immense program to excavate and reconstruct the canals headed by the Comune and by Insula, in order to shorten the unavailability of the entire

water network. In order to resolve this problem, the Comune proposed a plan of simple city navigation and assembled to review the transportation laws, with the objective of a definitive reorganization of the water traffic circulation taking into account the periodic essential features of the network.

The problem of water transport: the urban factor

The difficult work of adapting the historical network of the canals into an effective modern traffic model has already been mentioned. There are also problems of building degradation as a result of the moto ondoso. This problem, in general terms – the incompatibility of motorized traffic with the ambient quality– is characteristic of a contemporary urban system, the case in Venice is due specifically to two factors, the first, the urban development, the second, the modernization factor.

The first factor dates back to the age of the beginning of land connections with the mainland, the construction of a railroad between Mestre and Santa Lucia and the first translagoon bridge (1846). This becomes more obvious with the construction of the translagoon road and the beginning of automobiles in the Piazzale Roma in the 30's. The final step is seen in the beginning of the 60's with the introduction of the new island Nuova del Tronchetto, with the consolidation of the western city as the only access point between the people and the goods, and with the interruption of the circumnavigation of the floating city.



These changes reduce the original radial articulation of access from the outside to the city, with one network of inner connections between the main poles of Rialto, San Marco and Arsenale, and involve a monoaxial rigidity, centralized on the Grand Canal and the pedestrians parallel, along which the traffic is concentrated. The ancient canals function across the entire city and the water network is connected with the lagoon, on whose articulation the city was structured on long ago.

There have been a lot of adaptations of the pedestrian network to the new city organizational system directed towards the translagoon bridge. Little or nothing is changed in the structure of the water network, too delicate to be touched for greater architectural value, that is unavoidable to safeguard, but is surely underrated in its function of transport. Instead, the penetration in the heart of the city of the systems of land transport was assumed.

The last attempt of reorganizing the water network, in relation to the new system of Venice access, is the creation of the river Novo, contemporary to the realization of the automotive connection over the lagoon and Rome piazza, inaugurated in 1933, than it marks itself also as the last example of planning integrated of a system of transportation - infrastructures and means - even though limitedly to the collective transport of persons. It goes

remembered that this participation was preceded from a wide project debate, that the proposal of digging of another new channel saw contrasted on the spread director of traffic, naming canal Piccollo⁴, from the river of the Tolentini to the confluence with the river of ca' Foscari, that however would have demanded remarkable efforts of demolition in the Malcanton zone.

Subsequently, the plan of reorganization of 1939⁵ was written up by an engineer. Eugene Miozzi introduced interesting proposals of reorders to the transportation network, attempting to result in the reduction of traffic in the Grand Canal and to the fast connection with the external canals: the rectification and the increase of the Noale River in connection with Fondamente Nove, the reopening of the river terà of Sant' Agnese in connection with the Giudecca canal, the reopening of the river of Sant' Anna under Gribaldi street connecting between the river basin of San Marco and the Navi canal, the opening of canals in the zone of the Rome piazza, beyond to other smaller participation, between which some intermittent canals can be seen. The last occasion is the topic of new infrastructures for the water network to unite them with the urban level.

After 1939, the proposals have been limited to single objectives. As an example, during ` the national Competition of ideas for the formulation of the Urban Development Plan of the Comune de Venezia', the topic of the adaptation of the Noale River was brought up, and also appeared two new topics related to the improvement of the lagoons waters .

The first considerable intervention within the network of water transport was in the Galeazzo River, which enabled passing across L'Arsenale thanks to the opening of a passage in the building screen to the North with an alternative creation of a new canal parallel to that of the Nuove Fondamente, but within L'Arsenale itself, south of the public dry docks. It was finally realized, even though it was limited to public passage, with the inauguration in the summer of 1967 of the new line "Circolare #5." The second intervention previews the realization of a new canal between the River Novo and the Della Giudecca Canal driven by a preferential hypothesis,

as it were, by means of motors or by means of paddles. After the presentation of the General Regulatory Plan adopted in 1959, the discussions resulted instead in the abandonment of all the suggestions for aquatic matter and living things which sprang from the contribution of ideas. A proposal was put forth for a city that does not want to alter itself too quickly and that it could mechanize, modernize and energize at a high technical level with the circulation of motor boats. It would create a new canal with the functional characteristics of the Grand Canal, without the limitations, which would run from Punta della Stazione to the present point quickly unloading in the Guidecca Canal that part of traffic whose destinations are Zattere, Sacca Fisola, Giudecca, San Marco and others, until Lido. This new canal represents one physical continuation of the Grand Canal and permits, therefore, circulation around St. Mark's, the Grand Canal, Nuovo Canal, Canal of Giudecca. The entire structure of the traffic appears justified. The proposal did not find practical application and this function was used in the Scomenzera Canal which was gradually freed from harbor traffic.

More recently, from 1972-1992, talks were resumed regarding cutting across the northerly ____ of L'Arsenale to shorten the perimeter route around the eastern part of the city. The first project in this area, which is probably the most interesting, was introduced in a detailed plan that proposed a sharp cut to the original walls of L'Arsenale, framing one of the existing dry docks. At the end, the preliminary project of a new general regulatory plan of Venice of 1992 provided a variation from the PRG to internally link the Darsena Nuovissima of L'Arsenale with the Galeazze Canal. The recent establishment of part of the Giracitta ACTV lines that complete the circumnavigation of L'Arsenale provided for stops at San Pietro di Castello and at the basins of L'Arsenale, which renders these proposals particularly current and certainly suitable to decrease the time of the route covered.

The Problem of Water Transport – the Technical Factor

The second factor, technical in nature, can be traced back to the 1960s, a period in which the natural equilibrium between the infrastructure and means of transport is shattered, resulting in the growth of motorization and the increase in the number and size of boats. The first signs of the incompatibility between motorized traffic and building structures go back to the introduction of the first motorized boats at the end of the 1800s, the public service vaporetti of the Grand Canal line. After the first vision of lagoon and river connections between towns (Venice-Lido belonged to the town of Malamocco, and in 1868 put into operation the first public service vaporetti, Venice-Chioggia, Venice-Cavarzera, Venice-Fusina, Venice-Cavazuccherina, Venice-San Dona di Piave), on June 1, 1881, the first urban vaporetto entered in the lagoon to work in the Grand Canal, by government grant. If June 12 was the first test run, by June 20, the Venice Gazette published a letter in which detractors of the initiative for the first time raised certain subjects: the danger of navigation in the Grand Canal, the consequences created by the *motoscafo* brought upon by propellers.

Still famous are the protests from the gondoliers which eventually brought about the Strike of October 31, although the motive was essentially economic, for fear that the new competition in the public transport sector would dominate everything, for up until now, they were almost unopposed. For a long time, the vaporetti were among the few motorized facilities circulating the city, but the traffic problems started to worsen during the years between the two world wars.

Going back to 1925, a town regulation provided iron limits for the *motoscafi* destined to travel the internal canals, that they could not have a motor with more strength than 16 horsepower if it was gas-powered and 6HP if it was electric, nor could they transport more than eight persons.

The explosion of private motor boats happened instead at the start of the 1960s, a period in which, according to the statistics of the times, the rowing/paddle boats were cut by half

compared to before the war; the motorized freighters practically doubled; and the pleasure boats with outboard motors multiplied approximately twenty-fold. In that period of time, moreover, it became more and more apparent that state laws that governed general navigation were insufficient, both internal and maritime, and were inadequate to deal with and resolve the typical problems of urban traffic. It included all the problems of traffic on any mainland city with the added environmental impact upon building structures.

In 1963, the new town regulations regarding the traffic flow of both rowing/paddle boats and motorized propulsion boats in the Grand Canal and also in the internal city canals had been approved by the Town Council for the implementation of technical specifications in the navigation codes, which had been put forth 11 years before. The regulations were initiated to deal with problems of motorized navigation, even if limited by some technical peculiarities of each boat, and did not directly deal with the issue of *moto ondosso*, but were actually intended to safeguard the public peace and quiet. They prohibited motorized transport during night hours; enforced silencing equipment for the containment of noise within 85 decibels up to 7 meters; prohibited the use of intensely loud signaling systems.

It is unique that in the general compliance with the rules of traffic routes, there existed a double standard in the system of passage in the internal canals: the boats with paddles/oars had to stay clearly to the left side constrained from rowing to the Veneta; meanwhile, the motorized boats were expected to stay to the right side, with the resulting difficulty of maneuvering at a crossroad/junction in a narrow canal, in which case the motor boat had to move to the left. At any rate, the rules that contrasted with the general laws of navigation, forced one to stay instead to the center of the canal and not to the sides. This particular double standard was formally eliminated only in 1996, although the town regulation that was substituted had been in force for more than thirty years. In fact, it is actually practiced currently.

Nothing was said instead relative to the problem of the moto ondosso. It was dealt with directly in general binding terms with the introduction of differentiated speed limits based on the type of boat and service provided, from which emerged the order of public demand expressly relating to water traffic: group transport of people (public lines); individual transport of people (public, but not one of the lines); water taxi – (a service for the public and for different administrative tasks;) freight transport; and traffic for private or leisure use.

The problem in safeguarding Venice attracted dramatic attention of the world in 1966, when floods submerged the city and endangered its physical survival, subsequently, it could also be exposed in terms of water traffic.

The State responded with a special law in 1973 specifically targeting atmospheric pollution, the cause of the degradation/erosion of stone, and in respect to pollution, prescribed that all motor boats in the lagoon that would adhere to the antipollution laws for valid motorized conveyances within a two year deadline.

The Government commissioned the enactment of laws concerning the strength of the mechanisms of propulsion and of the necessary requisites to limit the pollution that came from them, anticipating that to make necessary changes to boats to limit hazardous pollution they were allowed special input. An appropriate parliamentary commission was expected, but nevertheless was never established, and the commission remained substantially unfulfilled.

A Search for Solutions: Planning motorized traffic and technological interventions. During the 1970s uncontrolled expansion of motorized water transport brought the City of Venice to the point where it had to deal directly with the traffic subject. The Communal Council on July 21, 1972 approved a document, Guidelines of the Administrative Council's Plan on the topic of the structure of the land. The title, "Communication in the Historical Center", reported the following glimpses: "Water traffic across the network of internal canals flows normally and

reasonably, not (affected) much with the opening of the new aquatic routes through the adoption of a system of one-way travel, prohibiting the parking and favorite routes of particular classes of water transport vehicles that prevents the overload and allows accessibility to every part of the city to freight traffic.”

After the initial experience of the introduction of the one-way system, borrowed from automobile traffic methods, it was given to a university work group to analyze the viability of the water network and to propose some solutions. The work group tackled the subject, believing in tangible adjustments in the water transport system and its routes and also in the possibility of using technical/scientific methodologies directly derived from the latter; keeping with the specifications with respect to the nature of the boats used, which had radically changing with respect to the period in which the network had originated.

On the contrary, in comparison with comparable land situations, the absence of private motorization gained recognition with a positive perspective on water traffic, because it was just a small number of boats compared to the number of automobiles circling in the city. It was acknowledged, though, that there was degradation to the building structures due to moto ondosos, a negative element in the distinction between water traffic versus automobile traffic, other things being equal, and in the problem of the inadequate network with respect to the question of mobility.

The solutions proposed were typical of an urban traffic plan before. Therefore, for a short period, they aimed for the optimization of circulation and movement, considering the moto ondosos only as a liability that reduces the function of the canal involved. The specific case was explained this way, as a normal problem of circulation, but also with the understanding of the need for radical intervention, for a fairly long period of time, beginning with urban maintenance to the management of urban structures. Individual study places importance on the problem of

freight transport and proposes the typical interventions adapted to the route circulations, the flow of traffic with a system of one-ways, adopting a movement pattern that at least lightens the load on the Grand Canal on the return route against penetration to the strained western bridge. Transit in the canals that are the most degraded is prohibited only to water taxis, classified as minor in social importance, which are intended for a wealthy tourist clientele.

But it was only in the 1980s that mere generalized speed limits were ruled as insufficient to deal with and resolve the problem of moto ondoso in the urban canals. In the 1980s, the Government Commission was reactivated to impose limitations concerning the strength of the mechanisms of propulsion which had been addressed in the special law of 1973. But this time the parliamentary commission established and pointed out the necessity of dealing with all the types of pollution produced by motor boats, hydrofoil, gaseous, from sewage and noise, identifying, first, a solution of differentiated speed limits, and second, the specific characteristics of a single technical class of boat, surpassing the legacies instead of the classes of transport or services performed.

The planning of water traffic

The most recent innovative element is the knowledge of the necessity to control traffic circulation with technological instruments, and still more important is realizing this in relation to the historical centers of the mainland with automatic control of the automobiles, and access to the zones which limit traffic. Continuous monitoring by satellite systems of boat services to areas of public interest and the use of control by means of cameras or systems of identifications can enforce limits, encourage a great self-control of boat drivers, and thus improve the relationship between traffic and the city.

Personnel Transport

Given the structure of the city, from the 1800's there has been a watery predicament between the people and the automobiles. Sometimes it is quicker to walk, in short distances. The structure of the canals has prevented the formation of a net of public transportation. Instead public transportation has evolved around the Grand Canal, and for over 50 years the short cuts were actually a lot quicker than the motorboats.



It is meaningful that until the introduction of the motorization of public transit, the water services were integrated with the pedestrian network through a system of ferries that crossed the Grand Canal according to the distances by land: during the second half of the 18th century, the Rialto bridge was the single stable connection between the two parts of the city. Connections existed but the service of long transport to cross the Grand Canal intensified substantially after the revolution to organize easier access to the city, to continue the construction of the railway connections and the station in the western part of Venice. Eventually boats were introduced and arrived with the departure and arrivals of trains²⁹.

Then came the introduction of a service line, which is characterized by frequent stops on opposite sides of the river. This substantially reduced the number of ferries and gondolas required, but they still exist as an alternative to the mechanized transport. The currently existing ferries travel from the Ferrovia to the Punta della Dogana, and some make stops at important

points (Santa Sofia al mercat di Rialto, San Tomà sul tragitto piazzale Roma- San Marco) while still more than 10% of traffic uses the Vaportetti line along the Grand Canal.

The services of gondolas for hire, already inaccessible to the greater part of the population, experienced a remarkable reduction. The motorization of taxis resulted in profession transfers from gondoliers to taxi drivers, which until stabilized, put 400 people unemployed, a substantial amount of people.

The development of mechanized public transportation remained absent along the canals of Venice for a long time, the Vaportetti introduced to the Grand Canal were the only usable means of transportation. For over 50 years the line grew smaller, the trip from Piazza del Roma to the Lido remained the only inner service to the city: the second (Rialto – Piazza del Roma- Saint Marc's Square- Lido) was inaugurated in the early 1930's with the opening of the Rio Novo. Public transportation along the Grand Canal was essentially to cater to tourists. The external connection ring, connecting Roma and St. Marc's, with the island of Murano and Giudeca, was finally introduced in the 1950's. From that time on public transportation only increased, proving its usefulness and increasing the number of boats and stops. For many decades, as a result, there has been an increase in canals connecting with the Grand Canal other than the Rio Novo. Like the short cut across the handle of Venice to the Rialto, these were not really any shorter, and only seemed short due to an increase in boat speed.

The perceived insufficiency during the 1970's led to the development of a hypothesis of circular functionality, according to several schemes. It is assumed that a circular service along the Grand Canal, from Roma-Rialto-Novo, would eliminate the damage caused by the stop of the Rialto (as boats continued to evolve) which caused problems in the community³⁰. There have been two more lines proposed to interlace in the River Novo that allow connection, that was

nonexistent before, between the external zones of the city and the inner zones, replacing the external circular line³¹.

In reality, the degradation of the canals and buildings along the Rio Novo-Rio di ca'Foscari has cost the city greatly. The direct line between the Piazza Roma and St. Marc's through the Rio Novo has been abandoned and now is run along the Scor-menzer and Giudecca, lengthening the time and distance, and the Grand Canal returned to be, after the 1950's, the only useable means for the line.

The maximum speed of the Vaporetti needs to be reduced from 13 to 11 km/h. The need for fast axial connections is reason itself for the restructuring of the canals in the last decade, the reduction of transport within the inner canals has begin being rationalized with the expulsion of direct connections and reorganization of the circular services. In this case they have also introduced new stops, creating better routes between the inner and external zones of the city, in particular between the canals of the Giudecca and the Grand Canal, through the new island of Tranchetta.

The popularity of the transport caught up with the capacity of the landings and new methods of transportation were designed oriented towards greater capacity with newer propulsion devices for reduced environmental impacts.

The progressive reduction of use of the city canals for public transport has taken forward steps, carried out with the motorboat taxi by now standardized with a maximum number of 20 people and therefore assailable, equipped with a powerful motor it could reach speeds higher than the 20 km/h limit, and a significantly reduced size to navigate the smaller canals of Venice which were previously inaccessible. At one time taxis only catered to the rich, giving rates far too high, then they eventually stabilized to about 200, and recently, by means of other factors (the increase of rates for non-residents, the saturation of the city's public transportation, the stretching of the

times and distances of the lines, the continuous movement of masses of tourists, the development of the airport etc.) the taxi service has become a service for everyone: the transport is therefore increasing, with the increasing hourly employment of motorboats that parallels the development of services, sometime amplified by drivers lacking proper licenses.

The idea of simulating the use of water taxis is still to this day insufficient for small canals. Residents, in recent times, have been quite aware of the limits of the inner canals, with the prohibition of nocturnal services, and the same Comune has come up with a prototype for a minitaxi that balances functionality with environmental awareness, thanks to reduced dimensions which allow it to travel down canals in which a normal taxi could not and it creates a low amount of moto ondosso.

In reality, the reduced speed from the River Novo to the Grand Canal, eliminates size of the motorboats, if not the number of vaporetti. The elevated element of incompatibility with the city is generally related to water taxis, because of their bad hydrodynamics at 5-7 km/h. The city's public transport now seems to have reached a relatively stable point of big problems and few realistic perspectives of solutions to reduce impacts.

The Transport of Goods

Much like the transport of personnel, the organization of goods transport, essentially city distribution, is mostly oriented to the east³². Localization of the only structure on the part of the Colombuola canal, continuing the Grand Canal beyond the railway station, the large director of distribution of the city is at the end of the Grand Canal, also the presence of guides that reference the limits of earth-water situated on land (Saint Giuliano – Canal Salso, Treporti) it is interesting that essentially all city canals go towards the North of the Grand Canal also utilizing the connections with the island north of Venice, mainly Murano.

In the specific case of goods transportation, the presence of lowered arch ways on bridges does not constitute a barrier, so long as the tide conditions cooperate. The problem of the city's good distribution effect on water traffic emerged in the 1970's after the first survey³³, and is very evident in studies by the Comune of Venice from the 1980's, during which it has been tested.³⁴ The last negative element of the infrastructure is the insufficient of usage of city canals for goods delivery. There is consistent congestion at the landings, is due to the scarce joints time of the distribution activity.

In order to resolve the first problem, the infrastructure characteristic and the therefore typical "affrontabile" of the Comune, is to come to the realization of a new center of "interscambio" at the "marittima" Station that, ultimately to the realization of stoccaggio warehouses today absent, to manage the goods distribution more efficiently. This renders competitive as well as the circular watery way that the city in alternative to the Grande Canal. For the second, instead, that it concerns the technical – economical organizations of transport, occupation essentially entrepreneur, and up to now preferred to take part itself on the effects rather than on the causes, with normal approach and relative obligation both for the maximum dimension (in particular wide and "stazze") that for the construction materials, (prohibition if utilities of iron of new construction, obligation of the "efficaci" shockproof equipments), then for the power (with limits in defined course). For the third party, and in course the reorder of the river systems landings with recovery of the situation already makes usable and the time separation of the conflict.

The exposed problem and the assumed cures for this problem are very difficult to identify, yet leads one to question the legal situation of the lagoon navigation system. The lagoon is not controlled by a single administration. The real problem resides in the Venetian Lagoon³⁵ state properties.

There is not one common authority which controls the inner city canals and the canals of the Lagoon Islands. This is the problem. The Scomerzera Canal, as an example of this, is an essential canal that connects the Grand Canal with the Giudecca Canal. Since this canal is classified as a harbor canal, it is controlled by the Harbor Master's Office. The River of Galeazze, which is an important canal linking the north of the Lagoon to the river basin of San Marco, is across from the Arsenal, and is subjected to the command of the Navy. The zones in the North of the City are under the Water Management.

With the growing urgency of this problem, the need to unify the navigation rules of the canals is extremely important, but difficult to accomplish. The different regimes, as it might be called, argue that different areas require different rules.

In the same prescribed power of Venice on its city water, the organization deputies have a voice in the marine rules and inner navigation of the canals.

Many years have passed without much being resolved regarding the laws which govern the canals. The Governo has recently decided³⁷ that the Providence of Venice will be coordinating the navigating of the lagoons with specific regulations in understanding with all of the local components and with the ministry of navigation, the work of the public and the environment, other than with the department of the city.

The esteem of the equality evolution of the water traffic and time

The ultimate problem of water traffic in the Venetian canal is attempting to determine where boats will get stuck in knots of the canals and deciding on a way to reduce problems associated with traffic congestion. As far as of the past water traffic goes, there is little trace that remains for the more available report and informal notes. In order to protest the insufficient impacts, in the city consequently the rivers and canals are entirely necessary, "rese" note the quantity of average traffic circulating daily on the San Polo river (the main artery intersection,

second design), consistently 89 bunches of cargo transport, 294 boats and 309 gondolas that transport people, for a total of 692 boats, entirely considerably decided that approximately a fifth of all the intersection are complex interesting canals. The traffic found in the same point 5 years after (1986) was approximately 500 boats: you can derive that the traffic in the past was actually quite intense, at least in the smaller canals, although it was totally compatible with the atmosphere, thanks to the propulsion to “remi”.

The system of traffic changed drastically at the end of the 70s, so consequently came the alarm for the increase of motorized traffic: the first scientific campaign was undertaken from 1977-1978, followed by a second carried out in 1986-1987. Worthy of a note moreover, the survey campaign carried out by Worcester Polytechnic Institute with the help of the UNESCO – Murst *the internal canal of Venice* between 1992 and 1994, they began to organize the data in computers following one scientific method at a time.

These campaigns were moreover the ones carried out in various seasons for an entire week at a station⁴⁰.

Unfortunately, the lack of a defined standard method was not always consistent to the volume of traffic in different period, volume subject for more to various meanings, there were not enough points, which made it very difficult to compare and in relation to continually find the order of the network: the unique sense of the institution was temporary to the navigation of the also important, and can also carry local imbalances in the distribution of the traffic that is not always rendered faithfully the total variation of the time movements.

If you examine the motor traffic that transits the Grand Canal in the rotten sense, in an eleven hour duration, from 7am to 6pm, in periods equivalent medium data regarding the stations, in the years 1978, 1986, 1987 and 1996, for which it has conclusive data⁴¹, excluding the ACTV. In the three sections of the Station, from the Rialto Bridge to the Accademia Bridge,

approximately 700 in 1978 to approximately 1200 boats in 1986 with an increment of 71% in eight years, corresponds to an annual rate of 7%, a successive year in 1987 shows that there were 1300 boats which passed (8% rate): Nine years later, in 1996, they found approximately 1450, which they believe will double in 18 years, which the increase will eventually slow down., which introduces an annual rate of 2%. Examining the Rialto Bridge, more positions all network, emerges the obvious variations of traffic in time: they give approximately 560 passages in 1978 to approximately 1250 in 1986-87 and then approximately 1700 in 1996. Of the individual motorized traffic in eighteen years there was more of an increase in the first decade (annual rate of 11%), in the second (3%).

Of the motorized traffic that comes to that comprehension of the ACTV passage, for to get the total motorized traffic in the Grand Canal to the Rialto Bridge, 300 transits in the eleven hours is a medium estimate. The total traffic around is 2000 boats, almost completely motorized.

Of the many boats that can be seen travelling daily through the canals in Venice, they fit nicely into 21 categories. The first two types are reserved for cargo boats, large and small, respectively. Similar to delivery trucks on the highway, these cargo boats travel the same routes over and over again delivering items throughout the city.

The third type of boat that can be seen on any day, in almost any canal in Venice is the public taxi boat. Due to the extremely high level of tourism in Venice, taxis are kept permanently busy traveling back and forth between the airport and hotels. Their business is increased more so by the greatly slower pace of land travel throughout Venice.

Not all travel through the canal network of Venice is public transportation, however. Privately owned personal boats can be seen as well. They are generally quite small in comparison, manned by one or two people, and have a tendency to travel more quickly than other larger boats. Unlike cars in a city, private transport is representative of a great minority. Even native Venetians opt to

travel publicly instead of using their own boats to travel more often than not. And if they are not going to take a public ACTV boat, they are still more likely to walk.

Appendix I: The Impacts of Traffic on Venice

As the use of fossil fuels rapidly increases alongside the development of newer mechanical technologies, we are constantly putting our environment in the way of potential harm. The smog in Los Angeles and Mexico City are prime examples of such harmful environmental problems. The air, however, is not the only part of the environment being negatively affected by our carelessness. The environment is constantly being exposed to various other types of pollution. Steps need to be taken in order to mitigate these harmful effects and help protect the environment in which we live.

While Venice's traffic paradigm is what makes it so unique and beautiful, it is the only place in the world whose method of transportation has the literal ability to destroy the city. The wake pollution caused by the abundant use of boats for transportation of goods, people, and resources is continually eroding the canal walls and chipping away at the foundations of the city causing it to sink.

In general, noise pollution has been shown to increase stress levels and blood pressure. Before motorboats took over as the leader in Venetian transport, there was little to no noise pollution resulting from boat traffic. Gondolas and rowboats contribute almost no noise whatsoever except for the occasional whistles, accordions, and singing gondoliers. Now that motorboats account for a large majority of traffic, the constant hum from passing engines can be heard at all times of the day. Boats such as taxis or small personal boats do not account for too much noise provided they are traveling within the posted speed limits and are not taking turns recklessly. This is where the problem lies.

It is interesting to note that one can accurately identify which boat is passing through an intersection by sound alone. Gondoliers always give a yell or a whistle as a sign that they are taking a turn and they wait for a response which would indicate another gondola is at the other

end of their turn. Cargo boats and trash boats typically slow down drastically and often come to a full stop before taking their turns seeing as they are large boats and frequently require wide turns. A large contributor to noise pollution, though, is the manner in which many taxis and small personal boats take their turns. Unwilling to slow down, many drivers prefer instead to lay on their horns beginning from the start of the turn and they do not let off until they have completed the turn. What is worse is that occasionally there is another boat coming from the other direction that has no choice but to duplicate this response so the oncoming driver might be aware of its presence. The biggest issue with noise pollution is that it is a major annoyance which could be dramatically reduced if only intersection regulations were more strictly enforced.

Boat engines, in addition to creating noise, also introduce harmful chemicals into the water and air. Increased levels of hydrocarbons have been found in samples of wildlife in the Venetian lagoon. In addition to harming wildlife, the water is unclean for contact with humans. Besides depositing dangerous chemicals, boats also constantly churn the sediment on the bottom of the canals which is primarily composed of human waste. As a result, coming into contact with the water poses serious health concerns. It is an unlikely goal to clean up the canals so much that they may be swimmable, but it is certainly within reach to mitigate the pile on of pollution by cleaning up engine deposits in an effort to provide a sustainable ecosystem in the canals and in the lagoon.

More obvious though, are the effects on the aesthetics of the city. The poor water quality and color detracts from the natural beauty of the canal network. Nobody doubts for a moment that Venice is one of the most unique and beautiful cities in the world, but invariably, the color and aroma of the water is mentioned as something that leaves much to be desired.

Through research, the causes of these contaminants can be better understood such that it will be easier to control and eliminate their harmful effects. Organizations such as Forma Urbis and

Coses have performed traffic counts to quantify Venetian boat traffic in an effort to construct a traffic model for the city. This model is intended to simulate traffic flow through the lagoon and inner canals of Venice with dynamic accuracy to account for potential closings and other variables. Knowing how and where boats travel makes it possible to gain a better understanding of the impacts of traffic on the environment in Venice.

Venetian traffic is significantly different from the traffic that most experience. Typically, car traffic during rush hour is due to the commute to and from work. However, in Venice, most traffic is due to public, personal, or goods transportation. 46% of traffic is made up of public taxi transportation. 36% is made up of goods shipments while the remaining 18% is comprised of private transportation. The leading contributor to Venetian traffic is the tourism industry. With 18 million tourists every year and growing, there has never been more stress put on the environment and Venice's 150 canals.

With the advent of motorboats, the Venetian canals have become repositories for engine byproduct. The exhaust of boat engines bubbles through the water and leaves behind hydrocarbon emissions. Similar to car exhaust being released into the atmosphere, these emissions are a detriment to the environment.

The evolution of motorboats into the Venetian canals has led to an observable increase in the amount of noise. As the boats travel through Venice, different engines at different speeds will cause varying levels of noise. Before Venice adopted motorized boat traffic, such noise was nonexistent. Now, it is unavoidable. Undoubtedly, this new noise pollution issue is something that needs to be addressed sooner rather than later. While noise pollution seems to pale in comparison to water and wake pollution, its effects can be great. It is well documented that prolonged exposure to noise can negatively affect ones hearing to the point of hearing damage and loss. One of the less known effects of noise pollution is its effect on cardiovascular health.

Exposure to moderately high levels of noise pollution during a single eight hour period, or typical work day, can cause a statistical rise in blood pressure due to a measureable increase in stress levels. Increasing vasoconstriction causes the rise in blood pressure, which is a main cause of coronary artery disease.

Measurements of noise levels produced by traveling boats were collected over a 16 hour period by ARPAV, the Agenzia Regionale Per la Prevenzione e Protezione del Veneto. The team monitored the Rio Novo over the course of the day with several microphones set up to record sound from different angles. Each observation was time-stamped such that the individual noises could closely be associated with the boat passing by at each moment. The overall goal was to determine how much noise was produced by each boat at varying speeds and angles.¹

Large cargo boats were the first boat type monitored during the study. Approaching from a 25 degree angle at 5km/h, they produced 74 decibels. This volume increased marginally as speed increased, but shoots up noticeably to 84.1 decibels when making a turn. Small cargo boats follow a similar pattern, although they are significantly quieter. Travelling at 5km/h, these small merchant vessels create 68.8 decibels. In a separation from their larger cousins, these boats are actually noisier when traveling quickly straight than when making a turn. When traveling at 10km/h, twice the posted speed limit, small cargo boats output 74.2 decibels. When turning, they create only 73 decibels.²

Public transportation accounts for a significant amount of Venetian boat traffic, and as such, taxis are found everywhere. The most common taxi model outputs 73.8 decibels when traveling in a line at 5km/h. When turning, however, they output 79.3 decibels. In this way they resemble the large cargo boats, but the difference between turning and travelling straight for

¹ <http://news.bbc.co.uk/2/hi/europe/6035047.stm>

² Comune di Venezia “Analisi dell’inquinamento acustico generato dal traffico acqueo nel Rio Novo – Rio de Ca’ Foscari” 2002

taxis is less significant. In fact, even when traveling at 10km/h there is only a difference of 3 decibels. ³

Less prevalent in the overall scheme of Venetian traffic are personal sport boats. They cannot be ignored, though. When traveling at 5km/h, these boats output 71.4 decibels, and when they are turning these boats output 78 decibels. In keeping with the trend of other boats, they too create more noise when travelling faster. ⁴

Of course, little can be said about noise pollution without traffic data to supplement the amount of noise outputted by each boat type. To this end, the noise pollution data collected by ARPAV ³ was compared alongside boat traffic counts carried out by COSES over the 2006-2007 years. The quantity of boats by type counted at each station was multiplied against that particular boat type's average volume output such that a total sum of volume per station was determined. Then, these sums by station were compared to construct a noise pollution index for the canals of Venice.

When boats move through an area, they first displace the water by pushing it away from the boat. Then, as they leave the same area, a gap in the water is left which is quickly filled in by gravity's effect on the surrounding water. This disturbance creates a wake, which can be devastatingly erosive to nearby structures. In general, this is not a problem, because the energy can disperse in large bodies of water. In the canals, however, where the width and depth is severely limited, this poses much more of a problem when the energy from the wakes is transferred into the canal walls.

The erosion of the canal walls raises an immediate concern to the structures on and around them. There have been many instances of buildings collapsing due to their structures being eroded from beneath them. A study was done that proved a significant amount of canal

³Ibid

⁴Ibid

sediment was an accumulation of building fragments which had fallen into the water. Not only is this a safety issue, but the city faces the danger of losing some of its historical beauty.

Wake pollution is rapidly becoming an unavoidable issue. The repair of the walls is quite expensive, ranging anywhere from 100 to 3000 Euros.⁵ Compared to motorized boats, human powered boats create little to no wake. Intuitively, wake pollution has only been a problem since the use of motorboats has become more prominent. The speed at which boats travel has a direct impact on the amount of wake they produce. There has been research done demonstrating that a 90% reduction in wake pollution can be achieved if boats traveled at the posted speed limits.

In 2002, a group of WPI students measured moto ondosos over a seven week period in an attempt to quantify wake pollution by boat type. They did this by measuring wake period, wavelength, and amplitude, as well as average speed by type.

Large cargo boats with a small payload output 1.84, 5.40 and 13.39 kg-m at 5, 11 and 20kmph respectively. They were determined to travel at an average speed of 13.39kmph and therefore output an average moto ondosos of 7.05 kg-m. It indicates a clear and direct increase of moto ondosos with respect to speed. This is mirrored in related examples. For instance, a large cargo boat with a high payload outputs 0.62, 5.44, 10.34 kg-m at 5, 11 and 20kmph respectively. Travelling at an average speed of 10.06, these cargo boats output an average moto ondosos of 4.25kg-m. The disparity in average moto ondosos between payload sizes is caused by the differences in average speed.⁶

The average moto ondosos output by boat type was calculated in order to determine which canals were most affected. The greatest contributor to moto ondosos by and large is the small cargo boats due to their extremely high average speed. Therefore, the areas where small cargo boats were prevalent tended to have the highest moto ondosos.

⁵“The Moto Ondoso Project: Assessing the Effects of Boat Traffic in the Canals of Venice” IQP, 2002.

⁶ Ibid

It should be clear that increased moto ondosos is the direct result of increased speed. In the aforementioned study, it was determined that only 3% of boats actually abided by the posted speed limits. Intuitively, more boats respecting the speed limit would drastically cut down the average speed, and therefore reduce the total moto ondosos output.