Increasing the Efficiency of Venetian Transport Systems for the Reduction of *Moto Ondoso*

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

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Abstract

Motor boat wakes is a pressing problem in Venice's canals. It poses a safety threat to smaller boats which risk being capsized, and erodes the canal walls. The goal of this project was to address inefficiencies in the Venetian boat transportation system in order to reduce wake production. Modifications to the public, taxi, and cargo boat systems were suggested and broken-down into a five-year plan which would result in a wake reduction of approximately 70%.

Executive Summary

It is inevitable that every big destination city has problems managing tourists and traffic, which can have many negative effects. One such example is Venice, Italy, which experiences millions of tourists annually and has a heavily used transportation system. This transportation system is based mainly on boats due to the fact that Venice is a series of islands with a canal system. These boats produce wakes or *moto ondoso,* which destroy the canal walls over time, causing structural issues. The *moto ondoso* also presents a safety issue, as small *gondolas* or sail boats are prone to being capsized by the high-amplitude waves. This project addressed the various transportation systems present in Venice in order to try and reduce *moto ondoso*, saving the structural integrity of the city's canal walls and maintaining safe water travel.

The transportation system of Venice is based into four main categories, of which this project will be evaluating public, cargo, and taxi transportation. The public transportation system accounts for about 21% of the overall transportation system, and consists of ACTV *vaporetto* boats and *Alilaguna* boats. The cargo boats account for about 36% of the overall system and are essential to delivering packages throughout the city. Taxi boats account for about 25% of the system and are used heavily by tourists, often going to and from the Marco Polo airport. All of these boats use a variety of hulls, many of which are not suited to the low-speed water travel present in the Venetian canals. This study first determined potential improvements to cargo transportation, then public transportation and taxi transportation. It then looked at how the hulls used by these three transportation systems can be improved to produce less wake at low speeds.

Our suggested improvements to the cargo transportation system centered around reducing the number of stops a cargo boat makes to deliver its goods throughout the city. According to a 2013 study, the boats in the cargo delivery system travel about 3,000km, or the distance from Venice to Iceland, to deliver about 32,000 packages throughout the city every day. The delivery routes are highly inefficient due to the way the delivery system is organized. Cargo is transported through the system *by product*, meaning that boats will pick up a particular type of product and will then go from stop to stop across a number of the Venetian islands to deliver a small number of packages to each. A study in 2001 analyzed the transport system and suggested a switch to *by location* delivery, where boats would be filled with the different types of packages going to one location and would go to just that single location. They split Venice up into 16 delivery zones, each of which would receive roughly even amounts of cargo. The 2013 study estimated this would reduce the distance travelled to 400km, or an 86% reduction in travel. This study also renewed the zone system, updating the 16 previous zones to be composed of 42 different zones using updated store and package delivery data. The City of Venice has built a warehouse, the *Interscambio Merci*, that was to be used to receive and

organize the cargo coming into Venice for switching to delivery *by-location*. It was built over a decade ago but continues to sit unused. The city recently put the warehouse up for bid to cargo consortiums with a €500.00 per year rent, but as of the end of December 2015, none had been accepted.

We sought to incentivize the switch to by-location delivery in the form of a rent reduction on the warehouse. Whichever cargo consortium wins the bid would have to organize their cargo transporters to act as efficiently as possible. Efficiency of their delivery routes would be evaluated and their rent would be reduced by a certain amount proportional to the increase in efficiency. To achieve this, a set of efficiency rules were developed based on *by-location* strategies, making them unachievable if cargo transporters were to continue using a *by-product* delivery system. The rules centered around minimizing the number of zones any one boat could go to each day, and making sure the boats followed the speed limit, as travel distance and speed are the primary components of *moto ondoso*. An example of such a regulation and the associated rent reduction is provided below.

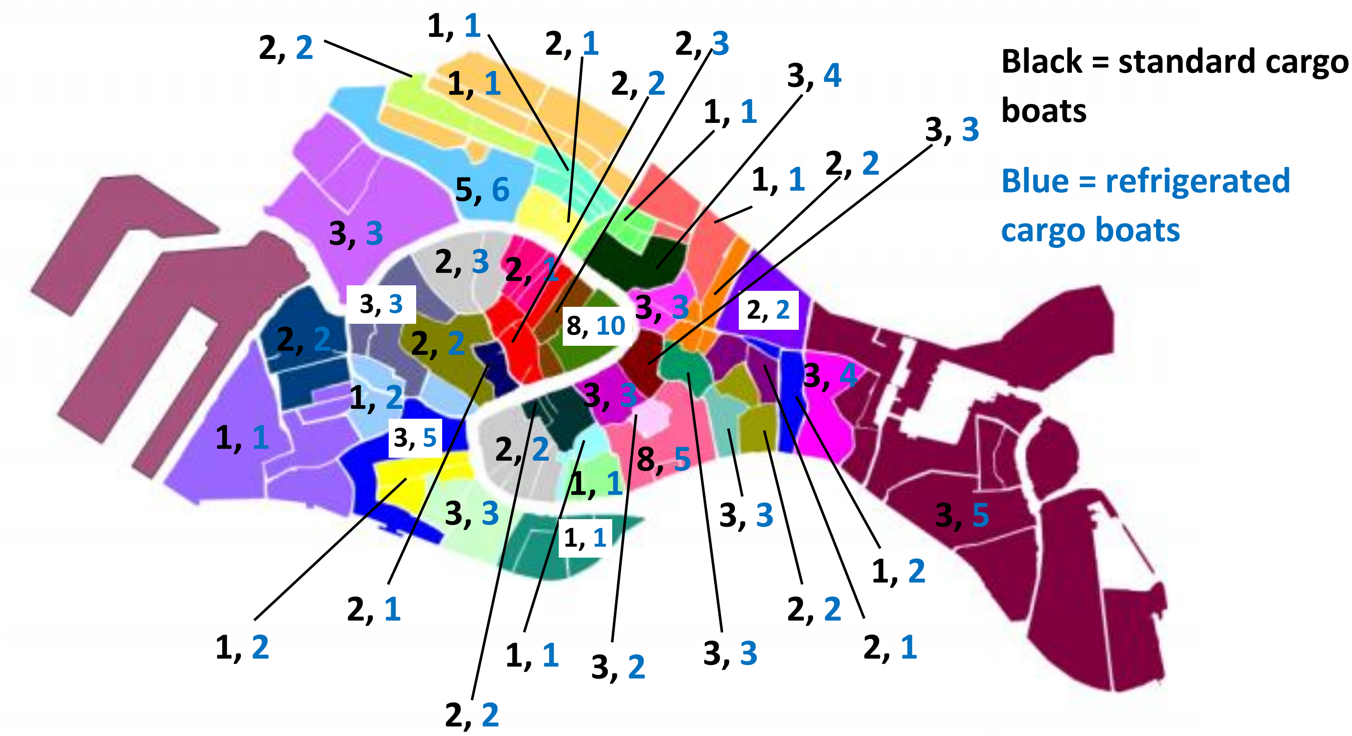
4 stops, 1 zone

☑ €467,000

4 stops, 4 zones

☒ €500,000

Additionally, the number of boats required for each zone was estimated using package volume and cargo boat capacity data from previous studies. By estimating how many standard and refrigerated cargo boats are required for each zone, further regulations were developed which would dictate how many boats the consortium would be allowed to send to each zone, contributing to the rent reduction. The number of boats per zone is provided in the figure below.



A GPS modules was used to test the feasibility of using such a system to track boats and their efficiency. Although we encountered issues using it on a cargo boat due to short battery life, travel was estimated by walking around Venice with the tracker. It was found that speed, stop, and zone information could be determined from GPS data and as such it is a viable system for tracking. Overall, the study concluded that an efficiency incentive system could be used to switch to a by-location delivery system, that the incentive would come in the form of a reduction in rent on the *Interscambio Merci*, and that a GPS tracker could be used to put this system in place.

Increasing the efficiency of the public transportation system in terms of passenger transportation from cruise ships was the second objective of this project. One past project determined that 25% of over 3,000 passengers per ship choose boat transportation, but increasing the efficiency of the boat transportation from cruise ships has not been addressed before. We found that this system is immensely inefficient, as nineteen of twenty-four total boats coming from two cruise ships were determined to be empty, while the remaining five boats were not filled either. Two of these five boats were double decker boats, one of which was 71% empty and the other 65% empty, and the remaining three of the five boats were

Alilaguna boats about 90% empty. These inefficient boat counts can be seen in the figure below. This is extremely inefficient because these boats are not transporting any passengers, and are therefore creating unnecessary *moto ondoso*.

We addressed this problem by improving the *Alilaguna Linea Blu* schedule and synchronizing it with the cruise ship arrivals, since *Alilaguna* boats are lighter and produce less *moto ondoso* than double decker boats. In order to increase the efficiency of the system, “bursts” of *Alilaguna* boats will be sent to the cruise ship terminal when a ship arrives. Each of these bursts will include an additional boat every half an hour for the three hours that it takes one cruise ship to unload. During each of these unloading periods, this would mean three additional boats per burst on top of the three existing hourly scheduled boats, totaling six boats per ship unloading. Furthermore, the bursts were synchronized with each cruise ship arrival so there was one burst per ship arrival. If 25% of the 3,553 average passengers per ship (889) choose boat transportation when unloading, then these six *Alilaguna* boats with a capacity of 160 each will take care of all applicable passengers. This system will be further synchronized by accounting for multiple ships per day, different passenger count numbers for different seasons, and by adjusting in advance based on updates about cruise ship cancellations or delays.

This system will eliminate unnecessary, empty boat trips by discouraging other boats from going to the terminal, and will ensure that boats are filled with passengers. The boats will be filled due to the increased incentive of the *Alilaguna* boats coming every half an hour during unloading times as opposed to the previous hourly basis. This solution will therefore make the overall boat transportation system for unloading cruise ship passengers more efficient and decrease *moto ondoso* production.

Currently, the taxi system contains several inefficiencies that increase the amount of *moto ondoso* in the city of Venice. Taxis are responsible for approximately 25% of *moto ondoso* within the city. Excessive amounts of wake are created due to inefficiencies within the system and certain regulations from the city. When on call, taxis must return to their stands empty after delivering customers to their destination rather than immediately picking up a new party. Some canals are also restricted from travel, making taxis have to travel a longer route to reach their destination. Taxis also cost 70-100 euro, making it one of the least used forms of transportation in Venice.

In order to increase the efficiency of the taxi transportation system, the total amount of miles travelled with passengers should be increased while the total distance travelled should be reduced. It was determined that ride sharing would address both issues. The process would involve separate parties riding in one taxi, getting delivered to their destinations, and paying a split rate. To establish the feasibility of ride-sharing, several rounds of interviews were conducted with tourists. Two interviews took place at the Marco Polo airport and Piazza San Marco with questions concerning tourists' trip length, transportation use, and ride-sharing preferences.

Of the 58 people surveyed, only 14 had used taxis while the rest used the ACTV and *Alilaguna* boats. When those who did not use the taxis were asked if they would consider using a taxi, 32 said they would not while 12 said they would. When asking all those who did not take taxis as to why, 38 said that they were too expensive while the other 6 had some lack of knowledge about the system; those lacking knowledge either did not know how to use a taxi or did not know that it existed. When all were asked what the minimum discount they desired to share a taxi, the majority wanted a 30% discount. The maximum time the majority of people were willing to wait for another party to join them and reach their destination was 20 minutes.

The results of the surveys indicate that taxi sharing has potential in Venice. We recommend that the rule preventing taxis from immediately picking up new customers after delivering their prior ones should be eliminated; this shall reduce the number of unproductive trips taxis make and thus reduce any unnecessary *moto ondoso* created. We also recommend opening up the *Arsenale* canal as well as create shortcuts to the airport and the cemetery the drivers will travel a smaller distance and create less *moto ondoso*.

Our last method of reducing *moto ondoso* was to change the boat hulls that are currently present in the city, so that they create less wake at lower speeds. Anything that floats creates waves, and the two factors that affect wave formation are hull shape and hull weight. Some of the boats that are currently in the lagoon are not necessarily ideal for the layout of the city. The maximum speed limit in the lagoon is 20 km/hr, and some of the planing hulls are only efficient past those speeds. There have been several previous efforts to create hulls that create less *moto ondoso*; however most of them have failed to do factors such as cost and political acceptance. Because of this, we had to consider several things before creating our new hulls. We wanted to make sure they created less wake, weighed less, cost around the same and looked the same. In order to create new and efficient boat hulls, we first had to measure and model the current boat hulls in the city. We did this by visiting several boat manufacturing companies and taking measurements and pictures of taxis and an *Alilaguna*. We then took these measurements and met with a local Venetian naval architect who taught us how to use Rhino, which is a 3D modeling software. We modeled the three boats in this program, and then changed the hulls to be more efficient. These changes included editing the bow, chine and keel as well as the overall structure of the boat. We then took the current and new hulls and ran them through a hydrodynamic analysis program called Maxsurf in order to get the hydrostatic parameters of the boats. The highest speed allowed in the lagoon is 20 km/hr therefore we took the resistance values for all the boats at this speed.

We were only able to run the taxi hulls through this program because we did not have enough time to run analyses on all of our models. Solely from changing the boat hull, we calculated that were would be a total increase in efficiency by about 19%. When we kept the boat hulls the same, but decreased the weight from our structure change, we calculated an efficiency increase of 10%. This would be a total increase in efficiency of approximately 29%. Due to the fact that we changed the exact same parameters across all of our boat designs, we can confidently say that the *Alilaguna* and cargo boats will also have about a 29% increase in efficiency. The two components of total resistance are skin friction and wave formation. Since we know the overall resistance decreased, we know the wave formation also decreased. In order to actually calculate the decrease in *moto ondoso*, a future study should be done to tweak our design and rerun them through Maxsurf. Then, scaled models should be built and tested in a towing tank to calculate the actual wave formation. If all goes well, our new hulls would be able to be sold to boat drivers within 5 years. Ideally, if our new hulls are bought, then the buyers would receive a discount from the city for being eco-friendly. In the future, all taxi, *Alilaguna* and cargo boats should be switched over to our new hulls in order to drastically reduce the damaging effects of *moto ondoso*.

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1. Introduction

Since the advent of motorboats in the 1960s, the issue of *moto ondoso* (boat wakes) eroding the canal walls of Venice, Italy has become more and more prominent. The main form of transportation in the city is by boat, and the wake created by these motorboats slowly erode the canal walls over time. This problem has been exacerbated by Venice becoming a primarily tourist-oriented city, as an increase in tourism leads to an increase in boat traffic. As can be seen in Figure 1, it is estimated that over 20 million tourists travel through the city each year, a huge number relative to the approximately 60,000 permanent residents.[1] According to a study from the Venice Project Center, there can be over 85,000 tourists arriving in Venice per day, with over 20,000 overnighters and 65,000 day trippers.[2] This places a heavy strain on the transportation industry, which in turn places a strain on Venice and its 150 canals.

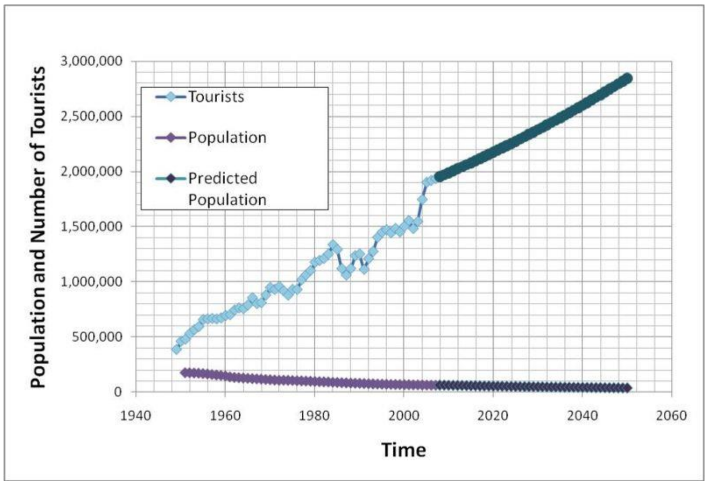

Figure 1: Permanent Residents vs. Tourists in Venice Over Time

One of the major costs of increased tourism is *moto* ondoso, the turbulent flow (wake) that is generated by an object as it moves through a body of water. In the city of Venice, wakes are generated by the taxi, cargo and public transportation boats navigating through its canals. Although wake may seem harmless at first, it actually poses several grave problems to Venice. For one, the continuous motion of water hitting the sides of the canal is the primary reason why Venice's canal walls are eroding rapidly. This was not a problem when manually-powered *gondolas* reigned supreme over the Venetian canals, but powerful motorboats have since supplanted the traditional form of transportation, and their increased energy has been followed by a subsequent increase in wake. This increase in wake production not only leads to

[1] (*Demographics* 2015)
[2] (*Demographics* 2015)

greater canal wall damage, it also poses a safety concern to smaller boats which can be pushed around and even capsized by the large wakes reverberating across the canals.

Moto ondoso has become a big enough issue that major social movements have arisen in response to it. A group named *Pax in Acqua* ("Peace in Water") was created in the early 2000's whose sole purpose is to attempt to reduce *moto ondoso* throughout Venice. Their *decalogo* ("Ten Commandments") include such objectives as enforcing the low speed limits which reduce *moto ondoso*, establishing systems for monitoring and controlling commercial boat travel, and replacing old and inefficient boats with newer models designed with wake-reducing hulls.[3] As seen in Figure 2, the local residents are already fairly well-versed in this issue, as it continuously shows up in local newspapers and several protests have been organized to address it.


IL GAZZETTINO

Venezia

V

LA REGATA Coppa del Presidente tormentata da continue "invasioni" di taxi e granturismo

Barche rovesciate, denuncia per **moto ondoso** in Bacino

LA RIFORMA Quasi tutti docenti dal meridione, ma i posti da coprire erano 406

Buona scuola, assegnate 80 cattedre

LE COPERTURE

Trecento insegnanti saranno precari

Figure 2: Local Newspaper Article Detailing the Issue of Moto Ondoso ("Capsized Boats, Complaints against Moto Ondoso in the Lagoon")

As far as addressing the issue, the city of Venice has mostly relied on repairing damage as it occurs, but more needs to be done to document and reduce the amount of wake in the city as a whole. In 2006 alone, canal wall maintenance cost over 35 million euros (~39 million dollars).[4] The city has built a warehouse in order to decrease the number of cargo boat trips and to increase the efficiency of the cargo transportation industry; the warehouse gives cargo drivers a place to sort the products by delivery location and then they can drop off the goods on a point-to-point basis. This plan is a major step towards increasing cargo efficiency, however the warehouse has been empty for several years and has yet to be used. Venice has also enacted speed limits around the islands ranging from 2km/hr. to 20km/hr. Even though they are generally obeyed within the city, they are not obeyed outside of the city in-between islands.[5] This poses a safety risk to other boats that have the potential of being capsized.

Several studies of boat transportation systems have been conducted in the past, addressing the issue of *moto ondoso*. One noted inefficiencies in the cargo delivery system, and recommended that the current system of delivery by-product be changed to delivery by-

[3] (Il decalogo di Pax in Acqua 2006)
[4] (Bossalini et al. 2013)
[5] (Chiu, Jagannath, and Nodine 2002)

location, as this would save on trips required to deliver all parcels.[6] The project proposed the creation of a warehouse for sorting cargo at the *Tronchetto*, Venice's cargo loading area, which was built and is now undergoing a bid process to see which third-party will assume control of it.[7] Other studies uncovered inefficiencies in the way water-taxis are dispatched and used.[8] Addressing these inefficiencies while identifying could reduce boat traffic and, consequently, *moto ondoso* production.

The goal of this project was therefore to build on and combines these studies, suggesting ways to implement their recommendations while performing two new studies. These two studies were to find ways to improve the public transportation system, and to design new boat hulls less likely to produce *moto ondoso* at low speeds. Since each transportation system offers its own unique set of challenges, multiple solutions for each one were identified and combined into a single proposal for reducing wake in Venice over five years.

[6] (Duffy et al. 2001)
[7] (dott.ssa Vettori 2015)
[8] (Accosta et al. 2006)

2. Background

This chapter outlines the information necessary to understand the current issue of *moto ondoso* in Venice, and its contributing factors. It begins with a detailed description of each type of transportation system we'll be addressing in this proposal: public, taxi, and cargo. It continues with a section discussing the primary types of *moto ondoso*, and what causes it. This is followed by a description of its consequences, and what has been done to address it so far.

2.1 Water Transportation in Venice

Venice is a city that stands on water, and since its colonization citizens have travelled throughout the city by boat. Originally, row boats were used which then evolved into the gondola throughout the centuries. The exact date of the first gondola has been debated, but some historians date it back to as early as 697. The design of the gondola originated in Venice, as can be seen in Figure 3, was highly ornamental. They were fashioned with fanciful ironwork and had a very broad stern. This helped the gondolier improve positioning and steering of the boat throughout the canals. By the 1600s there were an estimated 10,000 gondolas being rowed throughout the city.[9] In 1768, a naval artist made an architectural drawing of a gondola as it was designed during that time period. It is almost identical to the present design and

Figure 3. Venetian Gondola

proved today's gondolas are almost exactly the same as they were in the 1700s, except in symmetry. At the end of the 1800s, steam-powered boats were starting to rise within Venice. Though the design of the gondola had been perfected by then, their use declined because of the superiority of new boat designs in regards to carrying capacity and speed.[10] In the 1960s, motorized boats began being used with the increase in tourism, and widespread use of the

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[9] (*Gondolas* 2010)
[10] (*Gondolas* 2010)

gondola declined for the purpose of travel. In Venice today, the main boat type is the motorized boat which is used for the transport of people and goods; the gondola is still used, but primarily for crossing the Grand Canal and for tourist sightseeing.

2.1.1 Three Types of Boats Systems in Venice

Today, the four main types of boat transportation systems in Venice are taxi, public and cargo; there are also a small number of privately owned boats. Boat use can be broken into five categories: tourism, leisure, service, cargo and gondola, seen in Figure 4.[11]

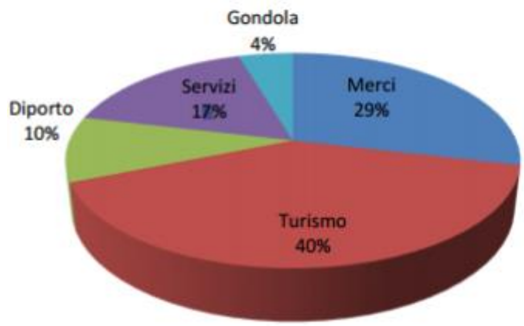

Figure 4: Types of Traffic in Venice

The main use of boats is for tourism accounting for 40% of traffic. The public transportation boats and taxis are used most frequently, by tourists and residents alike. We do not focus on private transportation because it represents a very small fraction of the boat traffic due to the high cost. Many gondolas can be seen throughout the city but are primarily used by tourists for city tours since they are quite costly and inconvenient for everyday travel. According to Figure 5, the most *moto ondoso* is produced by the tourism industry, indicating that this area should be more regulated.

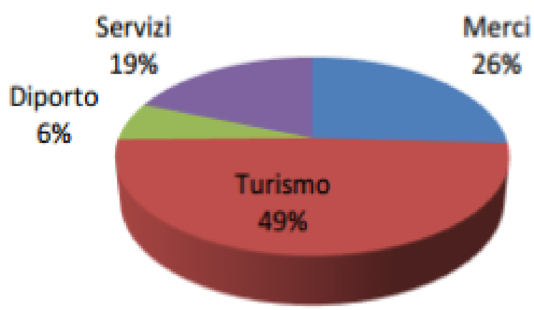

Figure 5: Moto Ondoso Produced by Different Types of Boats

[11] (Balboa et al. 2007)

2.2 Public Transportation System

One of the three main boat types that acts as a main contributor to *moto ondoso* in the city of Venice is public transportation boats. The most common term for the public transportation system in the city of Venice is "water busses". The two main types are *vaporetti*, and *Alilaguna*. These are larger boats that travel between predetermined stops based on a given schedule. The ACTV public transportation system can be seen in Appendix A, which shows the routes for the water busses throughout the city of Venice. This is operated by the municipal company "ACTV", which consists of 160 water busses. These water busses dock in at 120 different floating piers along the channels and transport over 95 million passengers annually.[12] This is the most popular means for daily commuting to work for groups of people throughout the islands of Venice.[13] This is true even for native Venetians, who choose this method over using their own boats for transportation. Along with taxis, water busses accounts for 46% of total traffic. This traffic is largely fueled by tourism, which generates 70% of Venice's yearly income. These public transportation boats are essential to catering to the 18 million annual tourists to get them around the city of Venice, and to and from thhe airport of Venice. This shows how big of a factor these public boats are in Venice and to the overall issue of *moto ondoso*.

2.2.1 *Moto Ondoso* Produced

Along with the high traffic, public transportation boats also contribute so heavily to *moto ondoso* because of their large physical size. The *vaporetto*, or "small steamer", is 24 meters long, has a 4.22-meter wide hull, and displaces 37 tons of water. The boat accommodates 200 passengers, and is available for 16 hours daily.[14] The *Alilaguna* boat is 22 meters long and has a 3.85 meter wide hull.[15] This boat goes between the mainland of Venice, the islands of Murano and Burano, and the islands of Venice, rather than staying primarily within the islands of Venice. This data shows how massive these public transportation boats are, therefore producing large wakes and contributing to *moto ondoso*.

Figure 6: A Public ACTV Water Bus

[12] (*Moving in Venice*)
[13] (Balboa et al. 2007)
[14] (Morandin et al. 2015)
[15] (Morandin et al. 2015)

2.3 Cargo Transportation System

The cargo transportation system is largely organized by *Consorzio Trasportatori Veneziani Riuniti* (CTVR). They represent about 70% of all cargo-transporters in Venice,[16] and encompass two of the three primary types of cargo boat which travel the canals. These include standard cargo, which encompasses everything from postage to food to laundry, and refrigerated cargo, typically composed of food or other temperature-sensitive packages. A third category, construction boats, contains highly specialized ships which are outside of the CTVR's management.[17] Combined, these three types of cargo boat represent between 25%-30% of all traffic going through Venice's canals.[18] [19]

Combined, these three types of cargo boat make up the core of Venice's "just in time" delivery system. Just in time delivery is a concept which abandons the traditional idea of buying and storing large amounts of resources locally to slowly use over time. Instead, items arrive as they're needed, typically on a daily basis. In Venice, such a delivery scheme is necessary due to the city's unique format and location. Since there is no land or space to store much of anything, imports to Venice are trucked in every day at the *Scalo Fluviale* and from there distributed to the boats which travel Venice's canals to deliver the goods. The *Scalo Fluviale* can be seen in Figure 7. Due to Venice's broad network of narrow streets and canals, there is no way to reduce the amount of cargo brought in by boats by storing it on nearby land and delivering it by foot.[20]

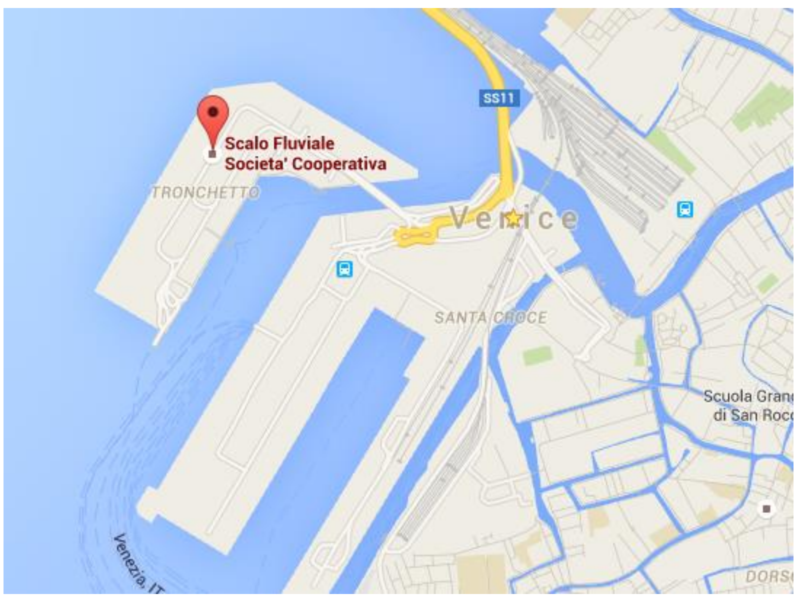

Figure 7: The Scalo Fluviale Pinned on a Map of Venice

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[16] (Duffy et al. 2001)
[17] (Duffy et al. 2001)
[18] (Balboa et al. 2007)
[19] (Bennett et al. 2013)
[20] (Duffy et al. 2001)

Standard cargo makes up approximately 72% of the CTVR's boats.[21] They also perform return trips containing goods going out of Venice, such as discarded packaging from earlier deliveries.

Figure 8: Venetian Cargo Boat

The refrigerated boats represent 28% of the CTVR's fleet.[22] Most of the space in this type of boat is taken up by a large refrigerated unit which keeps its contents cool. These are typically used for the delivery of perishable goods such as food, but can also contain medical supplies or any other item susceptible to heat; one of them even acts as a roving *gelato* vendor.

One of the big issues with these is that they are susceptible to refrigerants leaks which are expensive, dangerous, and pollute heavily. These refrigerants can vary in their composition, but include sulfur dioxide and ammonia, both of which can be dangerous to both human and animal life at even low concentrations.

Figure 9: Refrigerated Cargo Boat[23]

The final type of cargo boat commonly used in Venice is the construction boat. These boats operate outside the influence of the CTVR and are the sturdiest and heaviest type of

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[21] (Duffy et al. 2001)
[22] (Duffy et al. 2001)
[23] (Poganski 2012)

cargo boat. About 100 of them are currently in use in Venice.[24] They typically have a crane in the middle used to load and unload the materials being carried, and have the distinction of being one of the only boats which receive a special permit allowing them to be made of metal. This makes them much heavier than most ships operating in Venice, and they sit lower in the water. The result is increased wake during travel.

Figure 10: Construction Cargo Boat[25]

2.3.1 The *Moto Ondoso* Contributions of the Cargo System

According to two different sets of data gathered six years apart, cargo traffic makes up a large portion of the *moto ondoso* produced in Venice.[26] [27] As mentioned above, cargo represents 25%-30% of traffic in the canals, and the 2002 *moto ondoso* index study found they accounted for about 66% of the *moto ondoso* produced.[28] This nearly 2:1 relationship seems a bit high, but can be explained due to cargo boats being heavier and sitting lower in the water, therefore producing more wake. Additionally, boat speed studies in Venice show that cargo boats tend to have the highest average speed at about 13.5km/hr.[29]

2.4 Taxi Transportation System

The taxi transportation system is one of the most popular modes of transportation among Venetians and tourists, making it a significant source of revenue for the city's economy. Taxis are popular primarily because of their convenience: although customers must pay higher rates than they would for water-buses, taxis are more private and offer their services twenty-four hours a day, seven days a week. Taxis are available throughout the city at thirteen

[24] (Duffy et al. 2001)
[25] (Poganski 2012)
[26] (Balboa et al. 2007)
[27] (Bennett et al. 2013)
[28] (Chiu, Jagannath, and Nodine 2002)
[29] (*Moto Ondoso* 2012)

different stands and are capable of transporting passengers to and from the local airport. Fares are determined by a meter in the boat and change throughout the day, surging during particularly busy traveling hours and at later hours of the night. Several popular hotels around the city offer encourage taxi sharing among its guests by organizing groups of guests and scheduling their taxis ahead of time. Many taxi organizations require all of their drivers on call to pool their shifts' earnings and split them equally, making individual success completely reliant on the success of all the drivers.

A common Venetian taxi will usually be 1.3 meters in height, 9.0 meters in length and 2.2 meters in width[30]. Their hulls are made of either wood and/or fiberglass and their engines are 100-200 horsepower and use diesel as fuel. Most taxis can carry an average of eighteen people legally in their cabins. Like most Venetian boats, taxi boats are mostly built for high-speed travel meant for more open waters. There are thirteen taxi stands distributed throughout the city where taxi drivers stay while they are not transporting people. A normal call for a driver would involve the driver picking up his passengers, delivering them to their destination, and then returning back to the taxi stand to receive more orders. Currently, taxi drivers must return to the stand after delivering a customer before picking up another one. Many taxi organizations divide their drivers into teams and schedule workers by assigning different teams every few weeks in a cycle.

2.4.1 Inefficiencies Within the Taxi System

Although the Venetian taxi system is extremely convenient, it also has some inefficiencies that create detrimental effects on the city. The use of taxis is widely popular within the city, especially amongst tourists, contributing one-fourth of all motorized traffic in Venice and therefore creating a large amount of wake[31]. The system also has other inefficiencies when delivering passengers: most taxi drivers must return to their stand before picking up another client. This system leaves drivers with a large number of rides without passengers or fares, making it more difficult for all on the team to earn more money. In order to reduce the amount of wakes produced by taxis, Venice has already lowered speed limits and created harsher penalties for breaking water traffic laws.[32]

2.5 Boat Hulls & Design

The hulls that are currently being used in Venice, specifically taxis and private boats, are designed for high-speed travel which is not conducive to the layout of the city. High-speed

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[30] Bennett et al., "Boats are Waking me Crazy: An Analysis of Boat Traffic and *Moto Ondoso* in Venice."
[31] (Accosta et al. 2006)
[32] (Accosta et al. 2006)

travel is not appropriate for an urban environment as it creates an unnecessary amount of wake and poses serious safety concerns. There is a direct correlation between boat speed and the amount of wake it produces, different boat designs, specifically with hull shape, create different forms of wake. Travelling at lower speeds with certain boat hulls can actually create more *moto ondoso*, depending on the boat design, as shown through Figure 11. It also shows that different boats have different 'hump speeds;' each boat type has a certain speed at which the wakes they produce level off.[33] Travelling that speed or faster would produce less wakes than if travelling slower. This means that speed limits should possibly be different for different boat types, even though that may not be feasible.

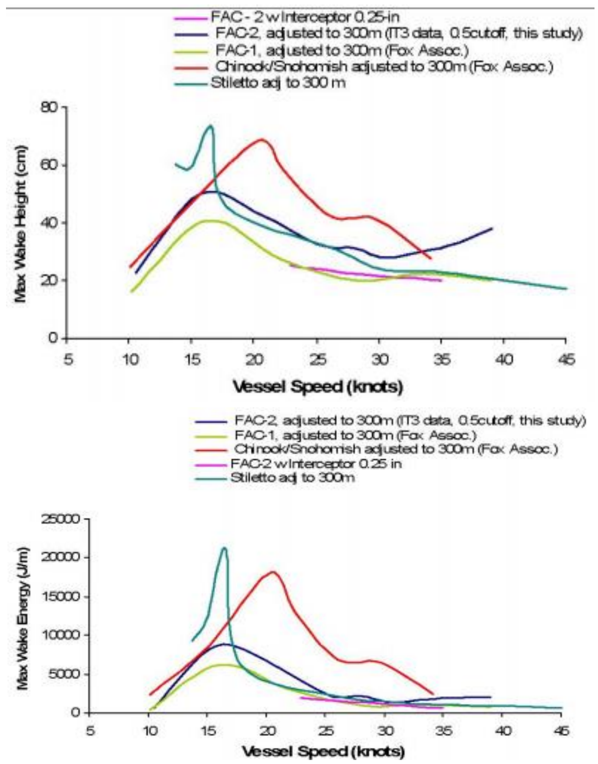

Figure 11: Comparison of Maximum Wake Height and Energy Variation with Vessel Speed

2.5.1 Vessel Pitch and Stern Draft

According to a study done in 2007 by IEEE, there is a direct correlation between vessel pitch and stern draft with the amount of wake energy and wake height produced by the boat.[34] Pitch is the rocking up and down of a boat, as can be seen in Figure 12. The more a boat rocks back and forth, the more waves it produces. Stern draft is the distance between the waterline and bottom of the hull (keel) including the thickness of it, indicated by the blue part in Figure 12. Having a smaller stern draft is important because it creates less *moto ondoso*. Figure 13 and

[33] (Osborne September 2007)
[34] (Osborne September 2007)

Figure 14 show that draft decreases with increasing speed, and pitch decreases after passing the hump speed of each boat. When these values are decreased, so is the amount of wake produced. Essentially, speed limits may not reduce wake for all boat types, and the design of the boat plays a major factor into the amount of wake it produces.

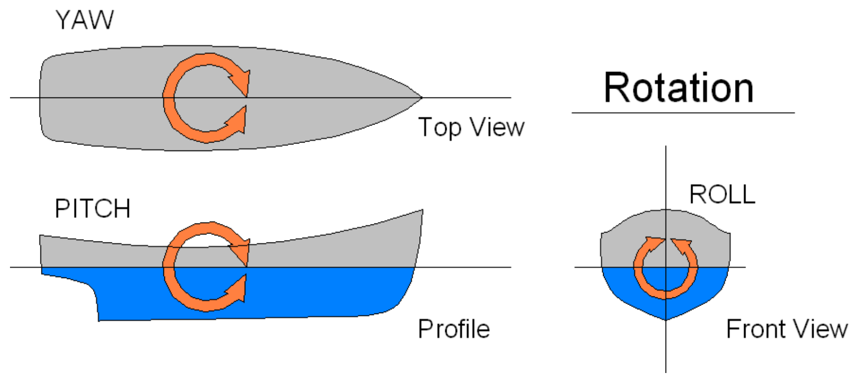

Figure 12: Pitch, Yaw, and Roll Explained

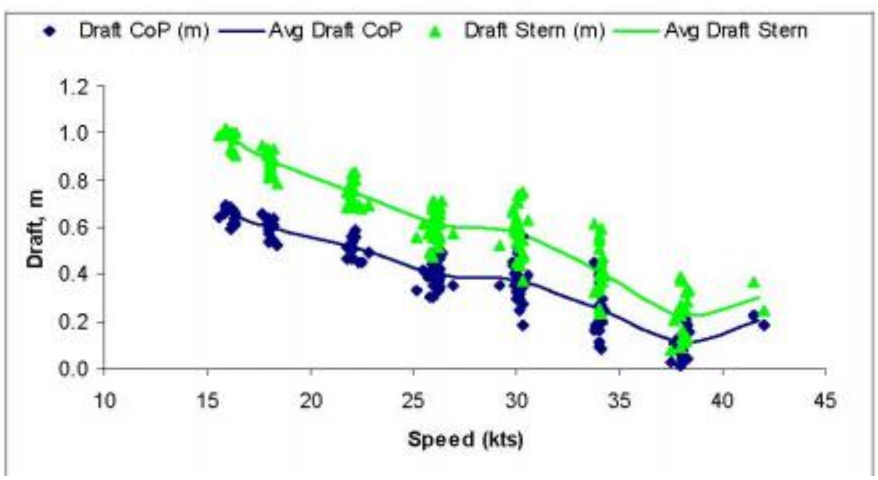

Figure 13: Variation in Vessel Draft with Speed[35]

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[35] (Osborne September 2007)

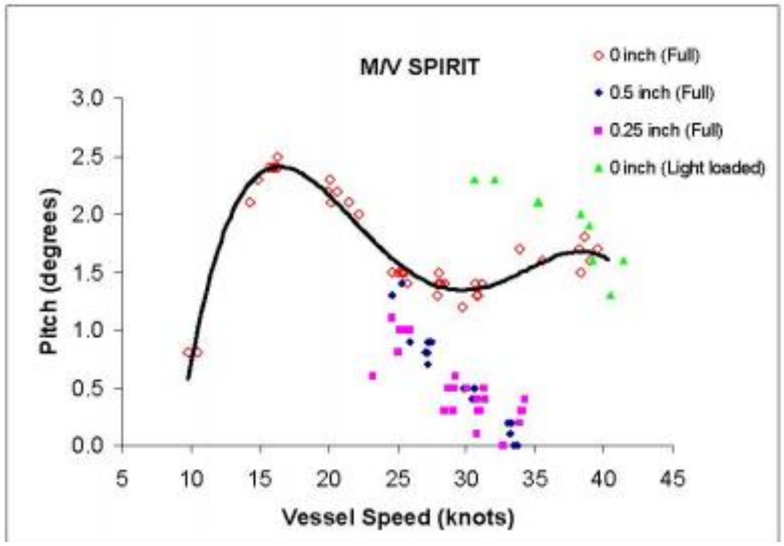

Figure 14 Vessel pitch and subsequent wake are reduced after a boat hits its hump speed[36]

2.5.2 The Deep-V Hull

The deep v-hull design of a boat involves the hull of a submerged boat having a slightly wider V shape. As can be seen in Figure 15, the angle of the deep-V hull ranges from 21-26 degrees, while a regular hull is around 15-20 degrees. This type of boat design keeps the boat more stable and helps it travel through the water smoothly. It increases the stern draft since more of the hull is sitting in the water, which then creates more wake. As seen in Figure 16 the hull creates less roll, the action of a boat rocking back and forth, and in turn creates less wake. This is an ideal design for high-speed boats, however once the boat starts to slow down it actually creates more wake and considerably more roll. The design of this boat is meant to keep the hull stable and travel safe at higher speeds and in rougher waters. The design is not ideal for the city of Venice because many canals have lower speed zones where these boats would create much wake and destabilize docked boats.

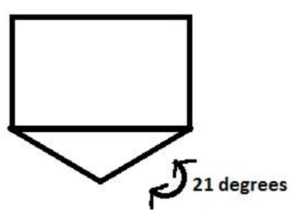

Figure 15: Deep-V Hull

[36] (Osborne September 2007)

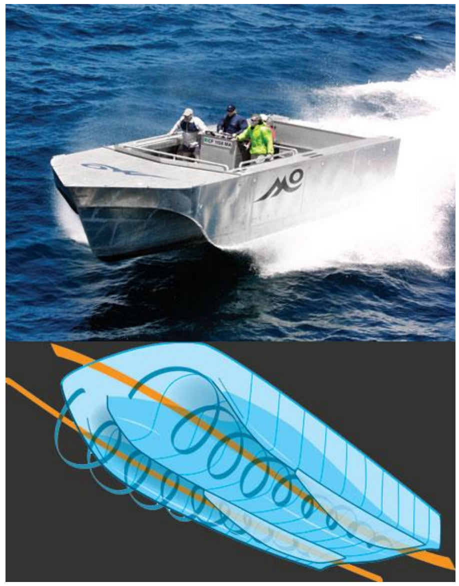

Figure 16: M-Hull Design

2.6 *Moto Ondoso* and the Damage it Causes

Moto ondoso is the Italian word for wake produced by motor boats; wake is the typically turbulent flow following a solid body moving through a body of water. Wakes take on the form of a V (Figure 17) and the source of their energy comes from the center of the boat. The two main manifesetations of *moto ondoso* are the height of the wave and the amount of energy each wave produces. Energy refers to the amount of energy it takes to move the object through the water. The waves will continue to disperse throughout the water until their energy decreases or they encounter another object such as a boat.

Figure 17 Wake Produced by a Motorized Boat

Turbulent flow is the unpredictable and chaotic changes in flow patterns of a fluid. It is dependent on Reynolds number which is the ratio of the momentum verses viscosity of a fluid; it has no dimension or unit and is a number that can be used to characterize flow patterns in a fluid. Turbulent flow exists when the Reynolds number (Re) of the fluid is above 4000; this value is dependent on maximum velocity, traveling length, dynamic/kinematic viscosity and the density of the fluid. If it is below this value then it is considered laminar flow, which involves the particles moving in straight, parallel lines in respect to one another, thus creating no wake. The differences between these two types of flow are represented in Figure 18. The energy from turbulent flow is extremely difficult to measure because of several factors including its high velocity and the fact that fluctuations in the flow occur every second, making it difficult to detect. Due to this, most analyses of wake are measured in experimental

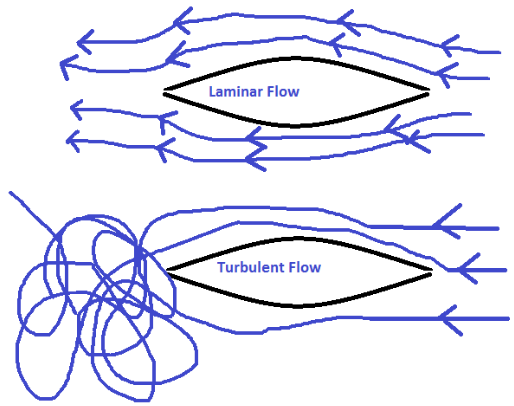

Figure 18 Laminar Flow vs. Turbulent Flow

settings. Any object moving through water will create a wake, even the smallest object; however, it tends to be negligible. The most wake is produced by motorized boats due to their larger mass, high velocity and hull shape; the values of these factors are directly proportional to the amount of wake produced. Wakes are a problem around the world because they can be dangerous to other smaller boats; many areas with high amounts of boat traffic are 'no wake zones.' Smaller boats can be capsized when there is a high wake amplitude. Specifically in Venice, they cause a major problem because they reverberate across the canal walls and create much damage.

2.6.1 Canal Wall Damage

Wakes cause damage to canal walls due to the increased force of flow. The force of the flowing water erodes the bricks and sandstone that make up the canal wall like a river carving through a canyon. Motorized boats create wakes that have higher amplitudes and higher forces, which erodes the canal walls at the water lines. Much of the heavy damage is on the lower portions of the walls because they have been exposed to the most wakes throughout the years, as seen in Figure 19.

Figure 19: Canal Wall Damaged by Erosion

Some of the boats create a large amount of turbulence underneath the water's surface, creating a vacuum-like effect on the walls. This is due to the amount of water that a boat displaces while it is moving. The volume of water displaced by the boat is equal to the weight of its hull. When the water is parted by the large mass of the boat, it eventually has to return to where it was, creating a vacuum effect and causes the sediment to be sucked out of the walls, causing more damage. The main culprit of the damage is the public transportation industry because the *Alilaguna* and *vaporetti* weigh a large amount. The erosion damages historical buildings that are centuries old and compromises their historical integrity. The city stands on its original infrastructure which makes replacing the canal walls impossible, without completely destroying the historical significance of the buildings and canals. Repairing the walls is extremely costly to the city, and requires shutting off entire canals at a time. In some of canals that are smaller in width, as small as 50 feet, the damage can be worse because the wakes will continue to bounce off the walls if they are in close proximity until their energy is lost or overcome by something else like another boat.

2.6.2 Safety Hazards from Wakes

Canal wall damage is the most prominent problem associated with wakes; however they also pose several safety hazards. Motor wakes can make smaller, man-powered boats and even small private boats unbalanced and can possibly capsize, creating potential risks of injury and dangers to the boats themselves. If a passenger in the boat falls out, even if they are wearing a life vest they are exposed to potential harm. Speeding tends to create more wakes in certain boat types; there is a direct correlation between wake produced and velocity. Although, the speeding limits are not as enforced as they should be, especially in the water outside of the canals. Speeding usually occurs in the areas between islands where there is not a noticeable police presence. If a fast moving boat does not slow down for rowers or other smaller boats, they have a high chance of capsizing as is show in Figure 20.

Figure 20: Wake almost overturning a Gondola

Taxi boats generally produce the highest waves along with other planning hulls such as ambulances and police boats. This is because they are designed to produce less wake at higher speeds, but the speeding limits restrict them, so they are actually producing more wake and higher waves at lower speeds. Collisions occur in the canals if there are too many boats in them at the same time. Typically, one boat will be stalled waiting for either passengers or goods and another boat will try to maneuver around them in order to get where they are going. If the canal is not wide enough or the wakes cause the other boat to unintentionally move, they may collide. Figure 21 shows an article about a boat that has been recently capsized by *moto ondoso*.

Venezia

Barche rovesciate, denuncia per moto ondoso in Bacino

Buona scuola, assegnate 80 cattedre

Figure 21: Article About a Boat Capsized by Moto Ondoso

Wakes also contribute to flooding on land in addition to the flooding the city experiences from heavy rains. Flooding is also a major problem for the city of Venice because it causes safety hazards to pedestrians and it damages its historical architecture, like the Piazza di San Marco which suffers from the effects of major flooding each year. The water levels in the canals will get extremely high when it rains, and when a boat passes through the canal, it will splash water up and onto the streets causing more flooding.

2.7 How *Moto Ondoso* has been Addressed So Far

There have been several efforts by the city of Venice in the past to control *moto ondoso*, including attempts to implement regulations. The main regulation that has been implemented is speed limits throughout the city. The speed limit depends on both the location and boat type. For example, the speed limit in the Canal Grande di Murano is 11km/hr for ACTV boats and

7km/hr for other boat types, and the speed limit is 7km/hr for ACTV boats in other canals and 5km/hr for other boat types. There is a difference in speed limit for ACTV boats due to the hull design, which produces low wakes. These wakes are the most destructive to the canal walls, resulting in the lower speed limits.

2.7.1 The M-Hull

The M hull design is a patented boat hull shape that helps create less wake and is a more efficient boat structure. The idea is that the water will flow through the boat instead of around it. This creates less turbulent flow, and more laminar flow which in turn creates negligible wake. The two channels within the boat that create the M shape cause the water to spiral which puts more oxygen into the flow. This creates less friction for the boat to ride on, giving a more efficient travel. It is a widely adopted hull design and is praised for its superiority in several factors such as minimal pitch, increased stability and stealth. A company in California designed and created a boat called the *Mangiaonda* which had this M hull shape, and would reduce *moto ondoso.* It was bought by the city of Venice and was first delivered in 2003, however, it now sits abandoned. The question is why it has yet been put to use, and why they have not been implemented around the city to reduce wake production.

The *Mangiaonde*, a M hull boat, was designed by American naval architect Charles Robinson specifically for the city of Venice. After being sold to ACTV for 450,000 euros, negotiations for another *Mangiaonde* began. At this time, the CEO of ACTV was replaced and put all of his efforts into discrediting the boat. The new CEO claimed the boat was inefficient and required too much horsepower to operate, increasing costs. He also claimed that carbon fiber, the material it was made out of, was flammable and went as far as faking test results to prove that it was dangerous. Later, ACTV tried to violate the *Mangiaonde*'s copyright by redesigning the boat with new dimensions. Their boat turned out to be less efficient and did not perform as well as the original M hull. Another company was willing to buy the original, but ACTV did not sell it out of fear that its proficient performance would make the public question why ACTV never used it.

2.7.2 *Interscambio Merci*

In 2001, a report titled *"Re-engineering the City of Venice's Cargo System for the Consorzio Trasportatori Veneziani Riuniti"*[37] was published, analyzing the best way to restructure the cargo system to reduce wake. The team concluded that the current system is highly inefficient as deliveries are organized "by product" rather than "by location," and

[37] (Duffy et al. 2001)

changing how boats are loaded with cargo and where they go would lead to dramatic efficiency improvements.

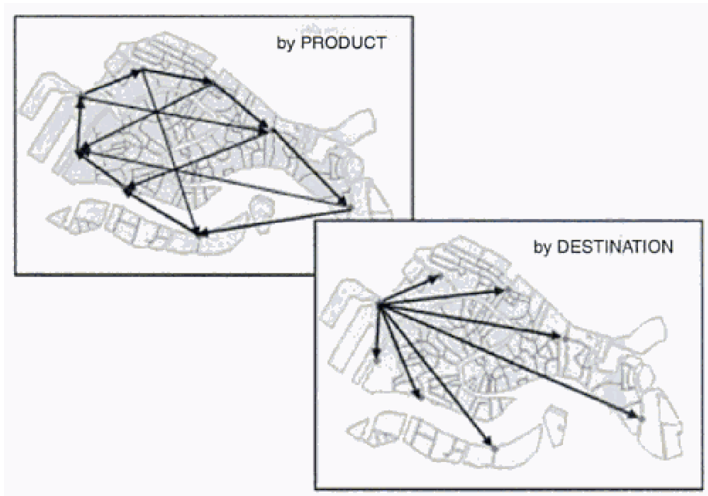

Figure 22: Cargo Deliveries in Venice: before (by product) and after (by destination)[38]

By doing so, boats would be assigned zones and their hulls filled with the cargo of all types going to that zone. They would have to make a single trip to that zone, and would be the only boats making that trip. This is highly superior to the current system, which involves each boat going completely around the city filled with a smaller amount of one type of cargo.

To organize this, the 2001 study proposed a long-term solution involving the building of a logistics warehouse. This warehouse would organize cargo into appropriate zones and load the boats going to those zones. Not only does this mean boats would have to travel less, it would also reduce the total number of cargo boats in the canals as more of them would be completely filled. The warehouse was built by the city of Venice over a decade ago, however, and sits unused to this day. If a long-term solution was successfully implemented, the warehouse would be by far the best way to implement a delivery by-location system, reducing the amount of *moto ondoso* produced by the cargo transportation system in Venice.

[38] (Fletcher and Spencer 2005)

3. Methodology

This project is intended to help the City of Venice reduce the *moto ondoso* or wakes produced by the cargo, taxi, and public transportation boats. To do so, we will investigate ways to modify these transportation systems in progressive phases to gradually reduce the wake they produce. Our proposals include not only modifications to the traffic systems, but also changes to the physical design of the boat hulls.

The main objectives of the project are to:

1. Reduce the distance travelled by each parcel in the cargo delivery system
2. Increase the passenger miles and reduce idle time of taxis
3. Reduce the public transportation boats necessary to ferry cruise ship passengers to San Marco
4. Identify feasible boat hull designs that reduce *moto ondoso* generated at low speeds

Our area of study focuses on the city of Venice as a whole, as all 125 islands and their canals are affected by boat traffic and the *moto ondoso* it produces. Figure 23 highlights where much of our studies will be focused. The *Scalo Fluviale*, circled in green, is where the cargo boats are currently loaded and the starting point of their route through Venice. The Grand Canal, in red, cuts through Venice and is where a large portion of boats pass through at one point, generating large amounts of *moto ondoso*. Finally, the Giudecca canal, in yellow, is where large public transport boats pass through to ferry cruise ships passengers to and from Venice, generating some of the highest, most dangerous waves. All of these are representative of where *moto ondoso* must be addressed, or where the most problematic boats come through. This study was undertaken during the Venetian winter season, from October to December 2015.

Figure 23: Area of Study

Efforts were centered on these contributors: cargo, taxi, and public transportation. Each traffic type was addressed through different solutions for reducing *moto ondoso*. The route planning and package paths of cargo boats were studied to see if packages were arriving at their destinations in the most efficient way possible. Ride sharing was investigated as a possible means to improve taxi efficiency. The public boat system was looked at to see what its contribution to the global *moto ondoso* present in Venice is. Finally, alternate designs for each type of boat was investigated in order to reduce the *moto ondoso* produced by the hulls.

The following sections describe the methods we adopted to accomplish the objectives.

3.1 Reducing the Distance Travelled by Each Cargo Boat in the Delivery System

The primary objective in re-engineering the Venetian cargo transportation system was to convert the current system of transporting parcels *by-product* to transporting them *by-location*. Currently, most of the cargo transporters are independent operators with a single boat. They typically load a certain product into their boat and then deliver that product to each of their clients, stopping at a broad range of cargo delivery locations throughout Venice. This leads to a very disorganized and tangled web of cargo transportation routes. A 2013 study analyzed the extent of this inefficiency, concluding that the cargo system delivered some 32,000 packages with a total combined travel distance of 3,000km, or the distance from here to Iceland, every single day. This transportation network can be seen in Figure 24.[39]

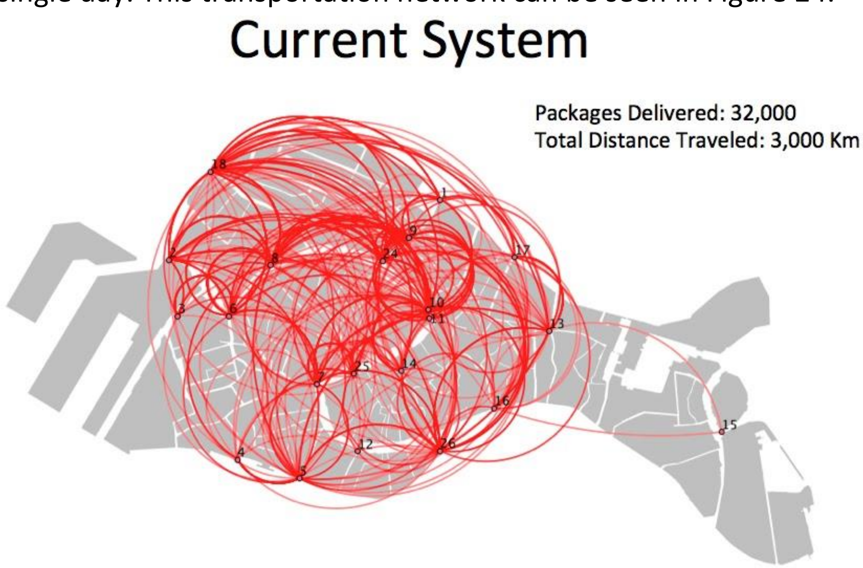

Figure 24: The Current By-Product Delivery Network

A 2001 study suggested that this system be changed to be organized by-location.[40] In such a system, the cargo transporters would load up all cargo going to a single location, and a boat would then go to a single location to deliver everything, rather than going to multiple different places. This would reduce the travel distance to 400km, or the distance from here to

[39] (Bennett et al. 2013)
[40] (Duffy et al. 2001)

Rome, as seen in Figure 25.[41] This is an impressive 86% reduction in travel distance, which would represent a similarly large drop in *moto ondoso* contributions of the cargo delivery system. The study also determined the cargo volume going to each island, and split Venice up into delivery zones receiving roughly equal amounts of cargo. The 2013 study updated the zone system based on newer retail data, and these updated zones are shown in Figure 26.[42]

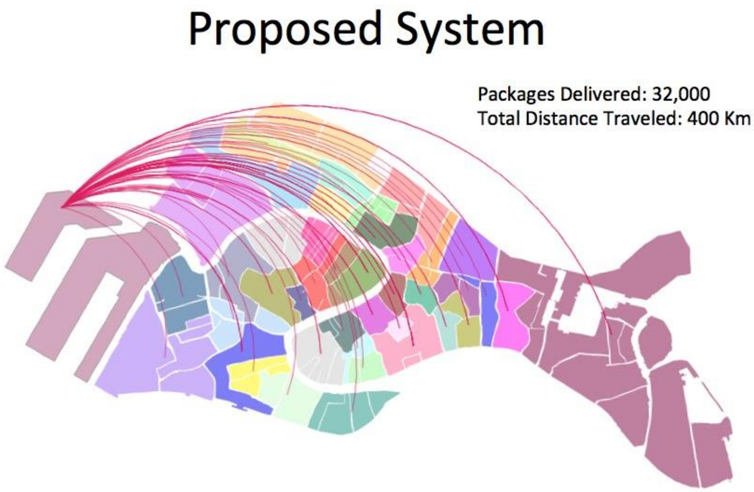

Figure 25: Proposed By-Location Delivery Network

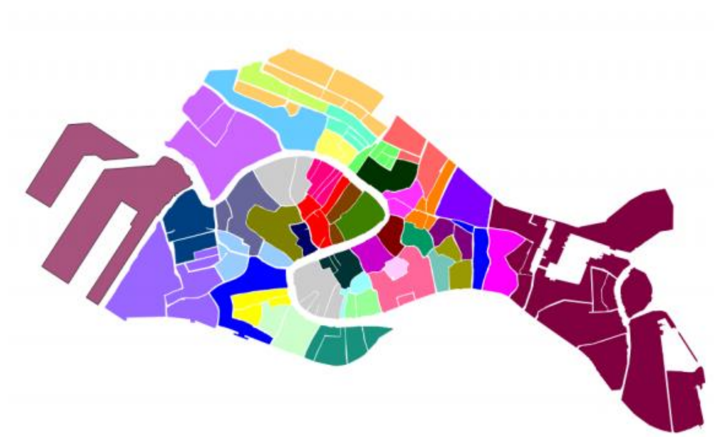

Figure 26: Venice Split into Delivery Zones with Distributed Delivery Volume

A portion of this project was focused on computing how many boats would be necessary to deliver the cargo going to these zones. If the delivery system is to be re-organized by zones, it would be necessary for the cargo consortium to know how many boats would be required, on average, at each zone. This will be determined experimentally over time as the boats go to each zone, but a starting point is necessary and thus a prediction was built based on past study data. However, this is only a portion of the cargo re-engineering portion of the project.

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[41] (Bennett et al. 2013)
[42] (Bennett et al. 2013)

The second idea explored by this project was to track and reward efficient travel. The tracking system analyzed the route and stops taken by a cargo transporter, and would then compare these values to those set by rules dictating cargo travel efficiency. This set of rules would aim to optimize efficiency by allowing them to be most easily followed if the delivery system was organized by-location. The reward, in this case would be centered around a warehouse built by the City of Venice called the *Interscambio Merci*.

Built following a recommendation by the 2001 study, the warehouse aimed to act as the central sorting location for Venetian cargo. However, it was built over a decade ago and sits unused to this day, making a by-location system impossible to implement. In 2015, the city published a request for bids to rent and operate the *Interscambio Merci*, setting the base rent at €500.000 per year.[43] The incentive for cargo transporters to follow the cargo tracking and efficiency system would be a reduction in rent for the consortium operating the warehouse.

3.1.1 Determining the Number of Boats Required per Zone

One of the crucial elements to re-organizing the delivery system to be by-location was determining how many boats would be necessary to service each island completely. To compute this number, data from both a 2001 and 2013 cargo study were combined. The 2013 study not only divided Venice's many islands into a series of 42 delivery zones, but it also estimated the number of packages that would be going to each island. It did this by combining the number of stores on each island with the number of packages each of these stores typically received, divided into standard and refrigerated goods.[44] This number could then be used with data from the 2001 study which measured what the average package and cargo boat size was, to determine how many boats would be necessary.[45]

First, the number of goods going to each zone was determined based on the per-island data. Since most zones were composed of several islands, total zone deliveries were computed by summing the individual cargo delivery volume going to each component island of a zone. Zones were then sorted based on which received the most or least packages in order to get a range of package delivery volumes. These volumes were then combined with data from the 2001 study to estimate number of boats necessary.

This earlier study determined the size and volume of both standard and refrigerated cargo boats, along with the volume of the average package. The volume of the boat was divided by the volume of the package to determine the number of packages an average boat could carry. These numbers were then reduced per study recommendations to avoid over-filling. For

[43] (Vettori 2015)
[44] (Bennett et al. 2013)
[45] (Duffy et al. 2001)

the standard cargo boat, 8m^3 were subtracted from the total storage space, and for refrigerated cargo, 1m^3 was removed.

With the number of packages going to each zone and the package capacity of each boat, the number of boats necessary was fairly straightforward to compute. The total number of standard and refrigerated packages going to a zone was divided by the carrying capacity of an average boat, and this value was then rounded up to determine the number of both standard and refrigerated boats going to a zone.

3.1.2 Developing an Efficiency Incentive System

Three important guidelines had to be followed when developing an efficiency incentive system. The first was that the system needed to emphasize the use of a delivery by-location system, as this was determined to be the most efficient way for the cargo transportation to be organized. Second, it needed to be easily quantifiable in order to translate the increased efficiency into increased reward for the cargo consortium. Third, but not least, was that the system put into place would need to be easily understood and followed in order for the cargo transporters to adopt and follow it, and for the governing authority to be able to easily analyze whether or not the rent reduction was justified.

To achieve this, the system was built around a set of rules. These rules dictated how cargo operators and consortiums should organize deliveries around the city, based on certain quantifiable efficiency factors. These factors determined efficiency by using numbers which would be completely different in a by-product vs by-location delivery system. They were split-up to be addressed at the individual boat level and at the consortium level. At the boat-level, the factors were as follows:

1. How many stops did the boat make?
2. Which zones were the stops in?
3. What speed did the boat travel at?

At the consortium-level, only one factor was identified:

1. How many boats went to a particular zone?

Together, these four factors were the basis for creating the rules that boats and the consortium should follow in order to get a reduction in rent. The rules identified are provided below:

1. A boat **is allowed** to go to one zone a day, defined as the first zone it makes a stop at
2. A boat **is allowed** unlimited stops to its zone
3. A boat **is allowed** to return to the *Interscambio Merci/Tronchetto* to pick up more cargo as long as it then returns to its initial zone
4. A boat **is not allowed** to go to any zone that is not its first zone
5. A boat **is not allowed** to go above a certain speed for more than a certain amount of time

6. The consortium as a whole **is not allowed** to send more than the pre-defined number of boats to a particular zone for the day

These rules were chosen specifically to create a path for the development of by-delivery location. By penalizing stopping at any zone other than the first, transporters which opt into this program are forced to pick-up and deliver cargo going to one location rather than jumping from zone to zone. There is no limit as to the number of stops in the first zone, as it's reasonable to assume that a transporter may want to deliver cargo at several different locations in the same zone since the area can be fairly large. Additionally, there is no penalty for returning to the first zone with another haul of cargo, as this would, in fact, be more efficient than having multiple different boats carrying the cargo to one zone. The speed rule was put in place in order to limit the extra *moto ondoso* produced at high speeds. The final rule concerning the number of boats going into a zone ensured some boats don't opt to travel inefficiently while all others do, and gives consortium management a goal to aim for when organizing the *Interscambio Merci*.

With these rules in place, the groundwork for a rent reduction system could then be developed. To do so, the rules were first broken down into the three primary points:

1. Did boats only go to a single zone
2. Did boats follow the speed limit
3. Did each zone not go beyond its allowed number of cargo boats

Each of these factors was assigned a maximum value of reduction, with the maximum amount only achievable with perfect efficiency. Efficiency was determined around the number of boats which followed the rules. For the former two, the percentage of boats which followed these regulations each day was taken and averaged for the month to determine the percentage of the reduction given. For the final factor, the percentage of zones which did not go above the allotted number of boats was taken and that percentage averaged over the entire month, similar to the previous two.

3.1.3 Testing an Efficiency Tracking System

To test a system for tracking parcels and measuring a cargo boat's efficiency, we selected a GPS tracker. The tracker was composed of printed circuit-board contained in a cardboard box for placing in a boat, and was built by a company called *Eraclit* owned by Oreste Venier, one of our collaborators. The current iteration of the tracker is still a development model, and as such it is a fairly large board which consumes more power than the final model would. An external battery was used in order to have the tracker record positional points for one day, and enough USB storage was connected to it to collect data continuously for that full day. This allowed the device to be placed on a cargo boat and have its position recorded during the delivery routes. The device can be seen in Figure 27.

To test this system, a cargo transporter volunteered to have the tracker placed on his boat. The device was given to the transporter in the afternoon, in order to ensure the complete picture of a delivery route could be recorded the following morning. It was kept in a safe, dry place near the boat's cockpit, where it had no overheard obstructions. The transporter was instructed to leave the tracker there without moving it around or removing it from the boat until pick-up the next evening.

Once the day-long trial period was over, the device was connected to a computer and its data downloaded. First, the data was filtered to only include position information during the times when the boat was actively making deliveries in Venice, between the hours of 12AM and 12PM**.** This data was then further subdivided into individual trips, with a trip being defined as a pickup and return to the *tronchetto*.

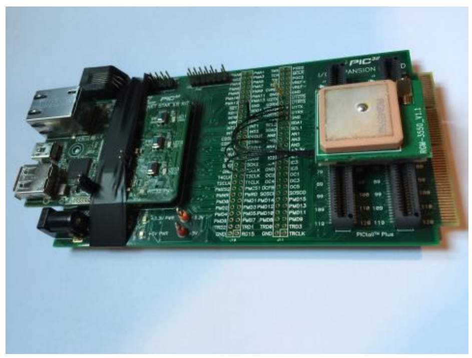

Figure 27: GPS Tracker

With the data split into appropriate trips, analysis could be performed on the cargo boat travel. Since each GPS point was associated with a timestamp, the average speed could be computed. To do so, points that were ten seconds apart were sampled and the distance between the two points used to compute speed. Additionally, the stops that the boat took could be identified by identifying when GPS points that were ten seconds apart did not move more than ten meters. This was considered a stop when six points in a row fulfilled that requirement, representing a sixty second pause. For each stop, the zone that stop was in was identified using the same map as in Figure 26. This analysis provided all the data necessary to see if all efficiency rules were followed.

Since only one GPS tracker could be secured, and was used for only a single day, the use of it largely served as a proof-of-concept to see if such a system would be feasible. Feasibility was determined simply by seeing if the data outputted by the GPS could in fact be used to extract stop and speed information. If such information could be extracted, a similar set of steps could be used to process trip data across all cargo boats in Venice and used in conjunction with the efficiency incentive system.

3.1.4 Identifying Ways to Misrepresent Efficiency Data

One possibility with tracking and incentivizing efficiency is that it might also encourage tampering with data to get desired results. Transporters might seek to artificially reduce their stop count or speed to receive the benefits while outputting as much or more *moto ondoso* as any other transporter.

To mitigate these issues, several possible tampering methods were brainstormed. Once a list of potential tampering methods had been identified, a further list of solutions to mitigate these methods was produced. Without necessitating further study, a general idea of the feasibility of these methods was established by answering the following questions:

1. Can the solution be implemented solely using algorithms based on the recorded data?
2. Does the solution require any sort of physical hardware that will have to be designed and attached to the boats?

These criteria then determined whether further study would be required to analyze the cost and feasibility of the solutions.

3.2 Increasing the Efficiency of Public Transportation from Cruise Ships

There has been much data collection by the Venice Project Center for the public transportation system throughout Venice in the past, however a gap still exists in this data regarding the boats transporting passengers from cruise ships. Past data does show that cruise ships are a main part of the influx of people to the city, as a 2010 study addressed. This project performed counts of 15,438 passengers from cruise ships over five days with fourteen ships, where they discovered that boats were the second most popular transportation option from the ships, as 25% (3,866) of these total people chose this method. It was also concluded that *Alilaguna* boats were the most popular and most advertised of the three available options of *Alilaguna* boats, tour boats, or water taxis.[46] This data shows the importance of public transportation in transporting these cruise ship passengers throughout the city of Venice. However, the gap in the data exists beyond this, in terms of how efficient these boats are in transporting passengers from the ships.

3.2.1 Cruise Ships Counts Used to Determine Efficiency Improvements

To go along with the 2010 project which stated that cruise ships can unload over 3,000 people at one time, data from the Venice *Terminal Passeggeri* shows that in 2014 there were a

[46] (Bellingham et al. 2010)

total of 488 cruise ships that traveled to Venice, with a total of 1,733,839 passengers.[47] If the total number of passengers is divided by the total number of cruise ships, this yields an average of 3,553 passengers per cruise ship, as is shown in Equation 1 below.

$$\frac{1{,}733{,}839\ passengers}{488\ cruise\ ships} = 3{,}553\ average\ passengers\ per\ cruise\ ship$$

Equation 1: Average Number of Passengers per Cruise Ship

However, since not all passengers take the public transportation system from the cruise ship, further calculations must be performed. The past study determined 25% of these 3,553 passengers will take the public transportation system, meaning 889 passengers suddenly coming from the cruise ship area would have to be accommodated for, as can be seen in Equation 2 below.[48]

$$3{,}553\ passengers * 0.25 = 889\ passengers$$

Equation 2: Number of Passengers Taking the Public Transportation System

This shows a very high concentration of people coming to Venice in a short time when each cruise ship arrives. In order to reduce *moto ondoso*, the efficiency of the public transportation system coming from these ships must be increased. This can be done by minimizing the number of trips made by the boats, while maximizing the number of passengers per boat.

To gather the data for these efforts, two students were stationed on the island of *Giudecca* and used binoculars to count the number of public transportation boats and record license numbers of the boats which came from the cruise ships carrying passengers, as seen in Figure 28. These students then communicated these counts and license numbers to two other students who were stationed at the San Marco boat stop, where the passengers arrived from the public transportation boats. These students counted people who arrived at the San Marco boat stop from the cruise ships.

Figure 28: Cruise Ship Count Area of Study

[47] (Bellingham et al. 2010)
[48] (Bellingham et al. 2010)

The purpose of this data collection was to see how many boats travel to and from the cruise ship terminal and how many of these boats carry passengers or are empty. With this data, we were able to see how efficient this system was, and how it can be improved. The counts of passengers departing public transportation boats at San Marco helped determine how full these boats were, from which utilization rates were calculated. The result of this was a redesigned system with increased efficiency to reduce *moto ondoso*.

3.3 Maximizing Passenger Miles of the Taxi System

In order to determine the current inefficiencies lying with the system, we reviewed the analysis and conclusions from a previous study on Venice's taxi transportation system. It was concluded that the taxi system suffers from inefficiencies such as picking up customers in only certain areas of the city and having empty cabins 33% of their operating times. Most taxis were also found to travel over the speed limits for short periods, creating an unnecessary amount of wake. Taxis also must travel less direct routes to certain places because there are several restricted canals in Venice and the boats detour around the outside of the city in order to reach their destination. [49]

Figure 29: Taxi Stands in Venice[50]

[49] (Accosta et al. 2006)
[50] (D'este 2013)

3.3.1 Ride Sharing

In order to test the feasibility of ride sharing, two parties need to be addressed separately: the passenger and the pilot. The passenger needs to be able to find people to share a taxi with quickly when he needs one, and the pilot must be willing to facilitate such an arrangement. Our goal was to investigate the interest in taxi sharing among tourists and local citizens in order to determine the feasibility of setting up such an option. Thankfully, ride sharing is no new concept in Venice and is already fairly accepted, so this project can focus primarily on simply proliferating rather than initiating ride sharing in Venice.

To determine if customers perceive organizing ride sharing at the taxi-stand level as beneficial, we had to interview an adequate number of people. A large enough sample size had to be obtained in order to properly represent the trends in a population, however we also realize that not many people would want to talk with us. We wanted to interview primarily tourists, since they are easy to identify and are more likely to use taxis than permanent residents. In order to obtain a suitable number of people to survey, we had to choose locations that would have a high density of tourists. We also needed an area where tourists could not easily walk away from us, such as popular tourist attractions with people waiting outside them with in lines.

After considering various areas that are popular among tourists, we selected the Piazza San Marco and Marco Polo airport to conduct interviews at Piazza San Marco was selected because attractions like the Basilica di San Marco and the Doge's Palace are popular tourist attractions and have lines extending outside. The square also has numerous restaurants and shops that are popular with tourists and is extremely close to ACTV, *Alilaguna*, and private boat stops as well as taxi stands. Marco Polo airport was also chosen for its high number of tourists. We also wished to interview tourists who were concluding their stays in Venice and had already rode on the various types of boat transportation, although we interviewed people both leaving and entering the city.

A pilot round of interviews was taken at Piazza San Marco to obtain a general reaction to taxi sharing and to test if the first draft of survey questions was sufficient. This round's questions can be found in Appendix B and consisted of four questions to keep the interview short and to keep the interviewee interested. The questions used in this interview were primarily about preferences on ride sharing, the cost reduction and waiting times. Using the feedback from the surveys and from the advisors, we reworked the questions to include four more, regarding their trip information, transportation information, and their ride-sharing preferences. The updated questions can be found in Appendix C. The surveys containing the updated questions were conducted at the boat docks of the Marco Polo airport. After determining that the number of people interviewed at the airport was insufficient, another round of interviews were conducted at Piazza San Marco again with the updated questions.

3.4 Designing New and Efficient Boat Hulls

Before we can start to design a new hull, we first must consider four things: the aesthetic differences a new hull may create, cost of the new design, the wake production and how much it will weigh. The new exterior design of the boat should not look drastically different from traditional models at water view. This is because we want native Venetians to be accepting of the designs, and they are less likely to accept them if they look different from what they are used to seeing in the water. The new cost of the design should not exceed a 20% increase because customers would not be very likely to purchase an extremely expensive new boat. The wake production and weight of the hulls should both by decreased by at least 10%. A decrease in weight would also lead to less water displacement by the boat, which would directly lead to less wake production. After the new boat hulls are analyzed, we will come back to these four criteria to make sure that we met our expectations.

3.4.1 Modeling Current and New Boat Designs

In order to improve boat design, we first need to know what the measurements are of a standard cargo boat, taxi and A*lilaguna*. To do this, we first went to several shipyards throughout Venice, including the *Serenella Cantiere Motonautico,* to take detailed pictures of these four boat hulls that we wanted to modify. We took measurements of the different boats in as much detail as possible in order to create 3D models. These measurements included but were not limited to the overall length, width, mid-ship height, chine length, height of frame, thickness of frame, the draft at the stern, longitudinal framing etc. These measurements were taken in centimeters with a measuring tape, the measurements were then written down and subsequent photos with the tape measure in the photo were taken. These measurements were then used to create 3D models of the three different hull designs we wanted to alter. After the photos were, with a baseline measurement, we turned to an expert on the matter of boat manufacturing Mr. Gregorio Giorgetti who is a naval architect and owns Giorgetti Marine, a company he runs with his brother. He first taught us how to use the program Rhinoceros, which is a 3D CAD modeling software. In this program we can take the measurements we recorded from the shipyards and create 3-dimensional models of the three different hull designs.

After we had the current boats modeled, we then changed three main parts of the design of the boat so that they would produce less wake. The first aspect we changed was at the bow. We wanted to increase the water penetration at the bow because as can be seen in Figure 30 Bad Water Penetration the boats in the lagoon have bad water penetration so the water is pushed outwards creating higher waves. We instead changed the bow, as seen in Figure 31, so that the water would flow around and detach from the boat, leading to better penetration and less waves.

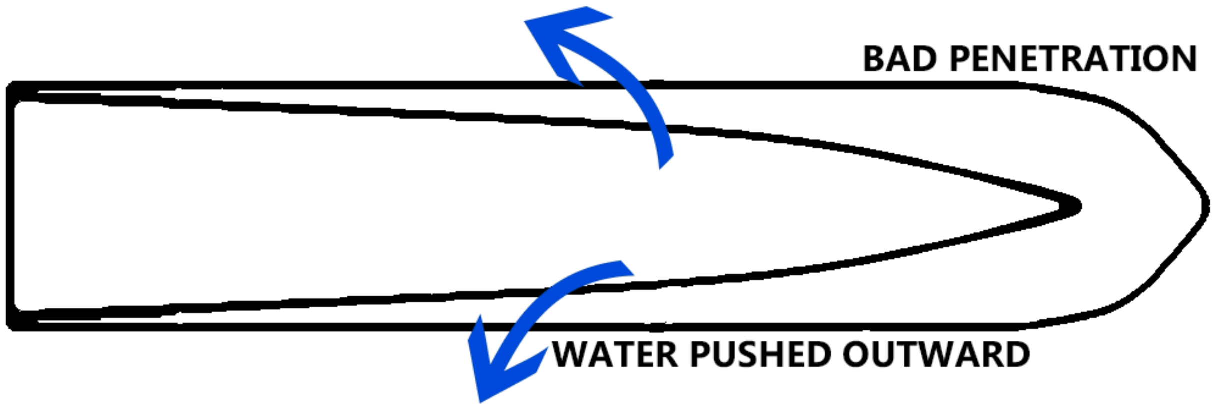

Figure 30 Bad Water Penetration

Figure 31 Good Water Penetration

The next thing we changed was at the chine. Figure 32 shows a hard chine which is at the top of the image, and it what the current boats have. A hard chine pushes the water down and outside the boat, which creates waves. Instead, we rounded the chine out so that the water would wrap around the hull and go back to the surface, creating more laminar flow and less waves.

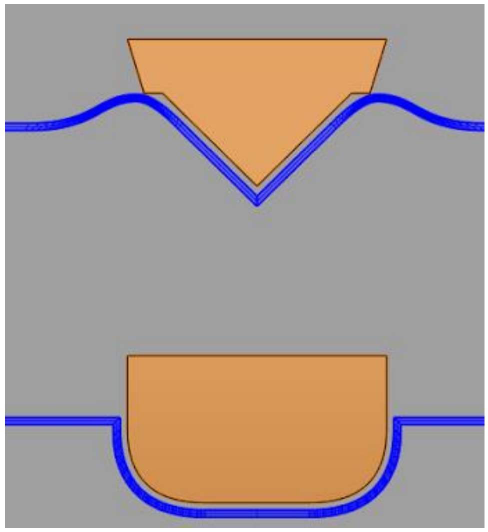

Figure 32 Hard Chine vs. Round Chine

The last thing we changed for the shape of the hulls were the keel. Figure 33 shows a straight keel which are what the current designs have, and create higher waves. We made the keel angled, as shown in Figure 34 so that the shape of the hull would contour the wave and create no waves.

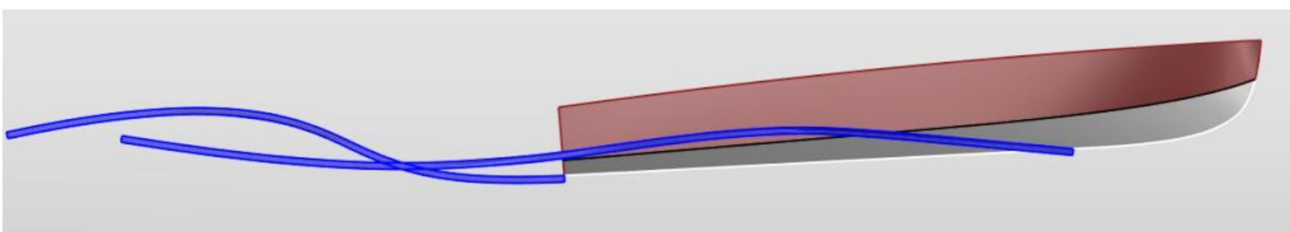

Figure 33 Straight Keel

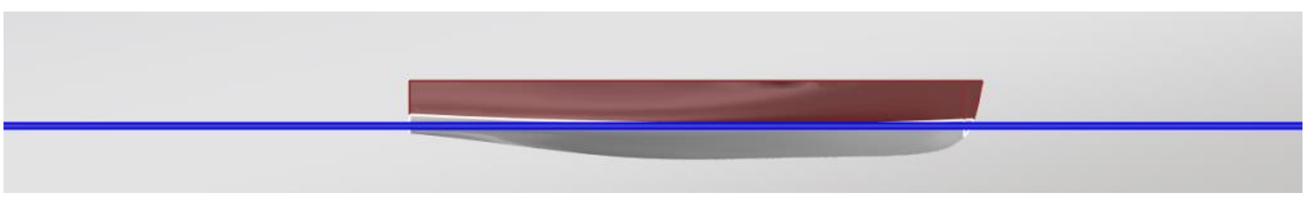

Figure 34 Raised Keel

The last aspect of the boats that we wanted to change was the weight. The reason we wanted to change the weight of the hull is shown in Figure 35. A heavier hull will sit lower in the canal. Increased weight amplifies the negative effects of an object flowing through water and creates a low-pressure field. This creates a vacuum effect and sucks the sediment from the canal walls. We wanted to create a lighter hull so there would be a high clearance from the bottom of the boat to the bottom of the canal. This would create a zero pressure field and would not suck the sediment from the canal walls. We did this by changing the structure of the boat.

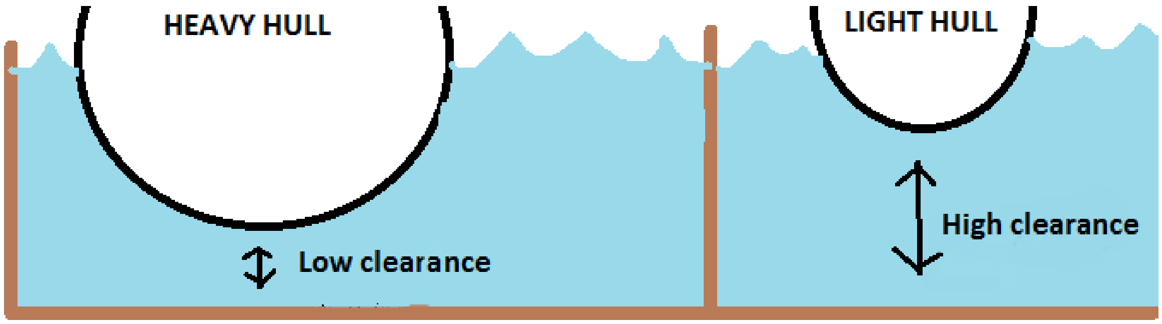

Figure 35 Water Displacement

All of these four changes were made to the three boat types, in varying degrees. Mr. Giorgetti then showed us how to use Maxsurf which is a program that analyzes marine vessels and helped us determine wake production. The hulls were uploaded into the software which gave us the hydrostatic parameters of the boats as well as the resistance values of the boat at certain speeds. We ran the current and new boat hulls as heavy and light hulls, and compared the resistance values, to calculate overall efficiency.

3.4.2 Improving Cargo Boat Design

Improving the design of the cargo boat was a difficult task. Any changes must not encumber the cargo space used to deliver the cargo, and alternate hulls may not have the same carrying capacity as the traditional hulls used. Another aspect we had to consider was making sure the new boats would still be able to carry refrigerated cargo since it takes up a lot of space in the boat. As such, we continued performing research on alternate hull designs such as catamarans and evaluating their potential carrying capacity.

3.4.3 Improving Taxi Boat Design

Taxi boats needed the most modifications because they are the least efficient and create a lot of wake. Two main aspects of the boat design that we looked at were vessel pitch and stern draft. In previous studies, we found that these two features are directly correlated with wake production. A new design that would minimize these, would hopefully reduce *moto ondoso* production as well.

When we discussed the taxi boat design with Mr. Giorgetti, he agreed that the taxi boats need the most changes. They are currently designed as planing hulls, which mean that at higher speeds they will overcome the waves they produce, and ride on top of them instead which creates less wake. Since these boats are actually running at lower speeds, the planing hull cannot plane, meaning its designing purpose becomes obsolete. We made the taxis into displacement hulls, so they work work more efficiently at 20 km/hr and below since that is the maximum speed limit in the lagoon.

3.4.4 Improving Public Transportation Boat Design

After speaking with Mr. Giorgetti, we determined that the public transportation boat design is actually rather efficient. While sitting on a smaller boat on the canal, we observed that when a public boat traveled by, the wake was visibly insignificant, however the boat rocked back and forth considerably. This is because the turbulent flow is mainly underneath the surface when it comes to A*lilagunas* and *vaporettis*. The high turbulence under the water hits the canal walls with great force. The height of the wake is essentially unnoticeable, but the damage is creates is the highest of the three types of boats. It sucks the sediment from the walls which erodes it at a higher rate. This creates a higher turbidity in the water, which is the haziness, and then increases the density of the water. The shape of the hull is actually rather good, and the Froude number is on the lower spectrum, which is ideal. The main focus of altering the public boats was to decrease the weight, as well as altering the chine, keel and bow. If the weight of the boat can be decreased, through alternative designs or materials, then the force with which the wakes hit the walls will be considerably less.

4. Results and Analysis

This section presents and analyzes the results of the procedures outlined in the methodology section. The results are explained and broken down using both text and visual aids.

4.1 Reducing the Distance Travelled by Each Cargo Boat in the Delivery System

One approach to reducing the *moto ondoso* from the cargo transportation system is to reduce the number of trips that cargo boats make by rewarding boat companies who take efficient routes. To assess whether boat companies are in fact being efficient, we needed to test a device that could be used to track their routes. As explained in Chapter 3, we tested the use of a GPS tracker for this purpose. The results of this test are provided below.

4.1.1 Determining the Number of Boats Required per Zone

The first step in determining the number of boats required per delivery zone was to identify the average number of packages going to each zone. The individual averages per island provided by the 2013 study were summed by zone in order to get the average delivery volume. Zone 8 received the smallest number of standard goods at 113 packages,[51] and also the least number of refrigerated goods at 20 packages. On the other hand, Zone 18 received the highest in both at 2677 and 520, respectively. In general, the number of dry packages greatly outnumbered the number of refrigerated packages. This data can be seen in Appendix V.

The second step was to compute the number of packages that could fit on the average cargo boat. The 2013 study concluded that a standard cargo boat had 35.7m^3 of storage space while refrigerated boats had 5.625m^3 of storage. With the average package size estimated to be 0.08m^3, the standard boats could store 447 packages and refrigerated boats could store about 70; however, these values were reduced to 350 and 57, respectively, in order to minimize over-filling and to give some room for bigger or oddly-sized packages.[52]

With these values, the total number of standard and refrigerated packages going to each zone was divided by the capacity of an average boat to get the number of boats per zone. It was found that generally, most zones would need between two and six boats total in order to satisfy all standard and refrigerated cargo deliveries. In fact, 83% of the zones would fit this requirement, with only seven zones needing more than six boats. This breakdown can be seen in Figure 36. Here, the labels represent the numbers of boat necessary and the size of the slice

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[51] A package is defined as an 0.08m^3 box representing the average size of a piece of cargo; (Bennett et al. 2013)
[52] (Bennett et al. 2013)

represents the proportion of zones requiring that number of boats. The complete set of data can be found in Appendix W. A graphic associating each zone with the number of boats required is provided in Figure 37.

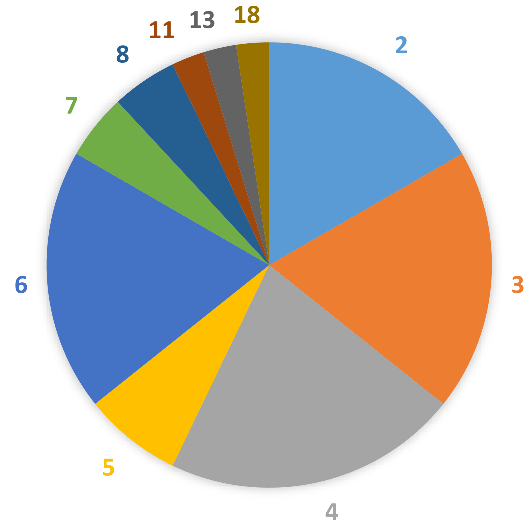

Figure 36: Proportion of Zones Requiring a Certain Number of Boats

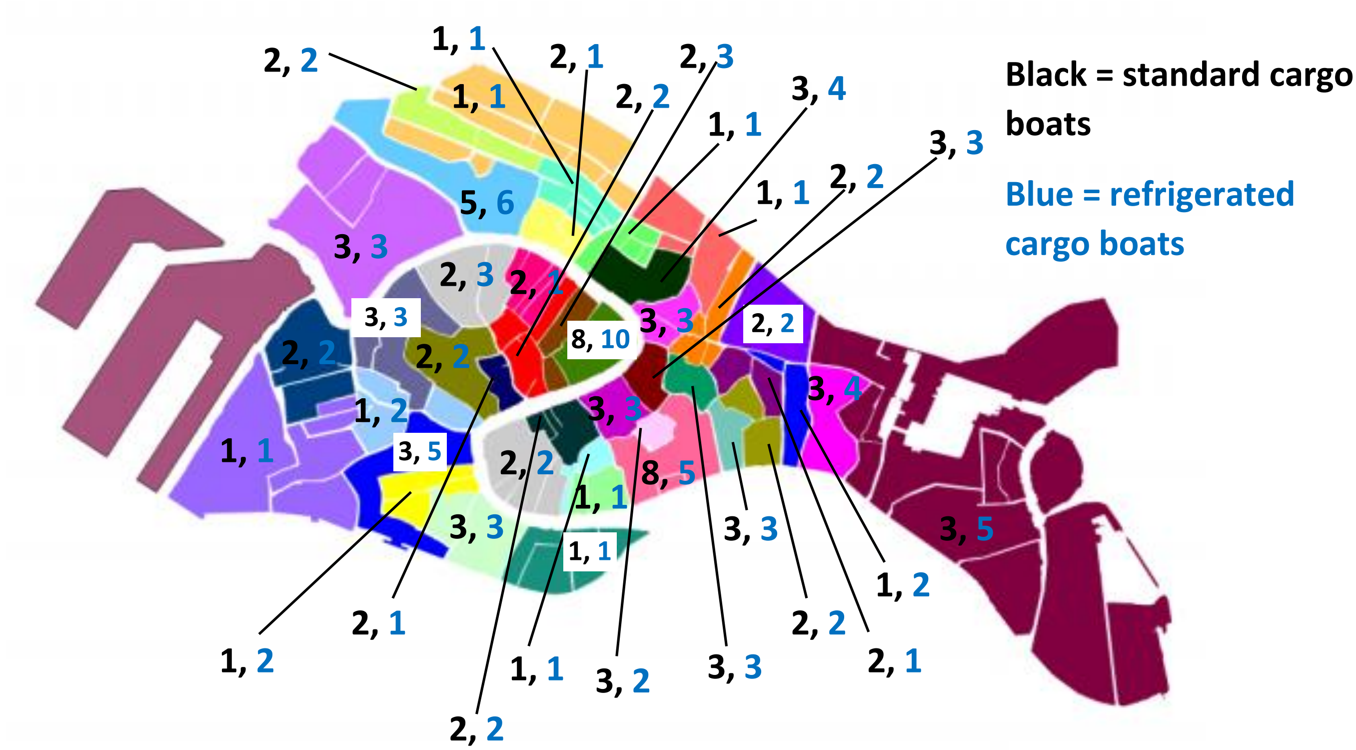

Figure 37: Number of Cargo Boats Required per Zone

In general, the number of refrigerated boats necessary for a single day was equal, and in fact slightly greater, than the number of standard cargo boats. Although this seems surprising due to the much larger volume of standard cargo, it should be kept in mind that a refrigerated boat has one sixth the carrying capacity of a standard cargo boat which would account for the similarities in number of boats required.

Related to this is the fact that some zones, surprisingly, require more refrigerated than standard cargo boats. Of the nine zones which fit this criteria, five, over half, are particular in that they're single-island zones rather than multi-island zones. Such zones exist due to the single island typically having a higher volume of pedestrian traffic translating to a larger number of commercial entities and delivery goods. Often, these zones have a large number of restaurants, gelato shops, or other food stores which all require refrigerated deliveries, rather than simple souvenir shops or other exclusively dry-cargo entities. The light blue zone top left labelled (5, 6), for example, along with the dark grey zone to the right of it near the Rialto labelled (3, 4) are both zones through which the *Strade Nova* passes through, a major Venetian artery through which tourists and commuters travel every day when coming from the train station. This street is wider than most, and has a huge volume of restaurants, patisseries, road-side food markets, and others. An example of a multi-zone area with more refrigerated boats required would be the dark red one all the way to the right, containing the *Arsenale*. This zone is much more residential, containing few touristy areas and is primarily composed of apartment buildings. Such a zone would have few non-essential stores such as souvenir shops, road-side tourist stands, or big clothes and fashion brands. However, pharmacies, restaurants, and grocery stores would all be important stores located in this zone and requiring refrigerated goods.

Another item of note is that many zones needed half or less than half of an additional cargo boat in order to fit all the packages going to that zone. In order to avoid having only partially-filled boats, the rules defined above may need to be amended. Instead of restricting all boats to only a single zone, certain zones could be paired based on partial delivery needs, and a boat assigned two delivery zones rather than just one for the day. In this way, partial deliveries could be consolidated to one boat going to both zones.

4.1.2 Developing an Efficiency Incentive System

Using the rules and efficiency factors outlined in section 3.1.2, a set of reductions and equations for determining those reductions were developed. In order to make these reductions meaningful to the consortium operating the *Interscambio Merci*, the upper limit on rent discount was initially set at €100,000 per year; however, to make the discount capable of being evenly split across the three reduction factors, the final value selected was €99,000. This would mean that each of the reduction factors would translate, at perfect efficiency, to a €33,000 reduction in yearly rent. Assuming that these savings accumulate on a monthly basis, each factor represents a potential €2,750 reduction in monthly. The three factors used are repeated below:

1. Did boats only go to a single zone

2. Did boats follow the speed limit
3. Did each zone not go beyond its allowed number of cargo boats

The equations developed to work around these factors each month are provided below:

$$Per\ boat\ zone\ reduction = \frac{\sum_{i=first\ day}^{last\ day} \%\ boats\ following\ zone\ restriction}{\#\ of\ days\ in\ month} * 2{,}750$$

Equation 3: Equation for Determining Rent Reduction Based on Zones Visited per Boat

$$Per\ boat\ speed\ reduction = \frac{\sum_{i=first\ day}^{last\ day} \%\ boats\ following\ speed\ restriction}{\#\ of\ days\ in\ month} * 2{,}750$$

Equation 4: Equation for Determining Rent Reduction Based on Speed per Boat

$$Global\ zone\ reduction = \frac{\sum_{i=first\ day}^{last\ day} \%\ zones\ at\ or\ under\ allotted\ boats}{\#\ of\ days\ in\ month} * 2{,}750$$

Equation 5: Equation for Determining Rent Reduction Based on Global Number of Boats Allotted to Each Zone

In these equations, the important quantitative value used to determine efficiency were the number of boats or zones which actually abided by the restrictions put in place. As seen in the first two equations, the percent of boats which followed the rules was averaged over the entire month, and that average was then multiplied by 2,750 to get the final reduction for the month. In the third equation, the idea was similar but since it was looking at the number of boats going to zones, the value which got averaged was the percent of zones which are at or under the number of cargo boats allotted to it for the day. Assuming all boats operated within regulations and the consortium always stayed within the correct number of boats per zone, the reduction on rent per month could go as high as €8,250. The zone restrictions are outlined in the figure below. Two different potential cargo boat paths are represented, with the accompanying rent reduction associated with each one outlined. Similar graphics were generated for the speed and zone boat allotment restrictions; these are provided in Appendix X.

Figure 38: Boat Following vs. Not Following Zone and Stop Regulations

4.1.3 Testing an Efficiency Tracking System

Although there was an unforeseen issue with the GPS tracking system, it was found that such a device could be used in an efficiency tracking system. The issue encountered was that the device's power usage was much higher than expected due to the device being in development, and as such the purchased 2600mAh battery only lasted two hours. After the device was placed in a cargo boat in the afternoon, it quickly died thus giving no useful data. To overcome this issue, the tracker was walked around in Venice using the streets, stopping at different locations along the way to simulate cargo boat travel. This data was then used to perform an analysis as to whether stop, zone, and speed data could be extracted from a GPS tracker.

The GPS tracker was placed in a cardboard box and data recorded by walking around Venice for a period of one hour. The tracker was kept horizontal with only a layer of cardboard on top of the GPS. The data gathered from this walk is displayed on a map of the walked area in Figure 39. The data is then summarized in Table 1.

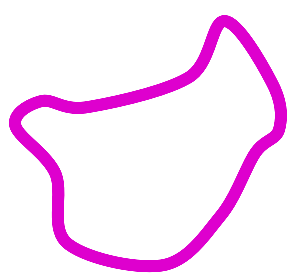

Figure 39: Map of Route Taken to Simulate Cargo Boat

# of Trips	1
Highest Speed (km/hr)	6.0
Time Spent Travelling Above 5.5 km/hr (secs)	43
Zones Stopped at	3
Stops Made at First Zone	2
Stops Made at Zones other than First Zone	2

Table 1: Summary of Cargo Efficiency Data

Our simulated use of the tracker indicated cargo efficiency data can in fact be determined using a GPS tracker. As evident from the high number of zone stops, this current route would result in a fairly low efficiency score. The simulated transporter did not abide by the single-zone requirement, in fact going to multiple stops at three others. He also failed to obey the speed limits and spent just over three minutes at speeds exceeding 5.5 km/hr. Taking this into account, the following efficiency percentages were computed:

4.1.4 Identifying Ways to Misrepresent Efficiency Data

There are several ways that the tracking system could fail and output bad data. These could be for a variety of unintentional or intentional reasons, and this data needs to be identified and removed from the efficiency computations in order to make sure that any rent reduction is justified. Three different methods through which bad GPS data could be generated are summarized in Table 2.

The tracker is on a different boat that goes a different route than the one being tracked *Interscambio*
The tracker is removed from the boat and not used to track the route
The GPS is unable to connect to the satellites or output correct positional information

Table 2: Methods for Tampering with Efficiency Data

What these methods have in common, is that they are fairly easy to detect. The first two have a common failure point, which is that they both require the tracker to be removed from its anchor point on the boat. By making sure that the trackers are non-removable, or that there is a detection system to alert a removal, these methods become useless. The second one is easily detectable since the GPS outputs information as to how accurate its position estimate is. The data could be parsed and any bad information thrown out.

The solution, therefore, would be to default to a standard efficiency value of zero when bad data is detected. Whether this is when a tracker removal is detected, or when the GPS has trouble getting a lock on the satellites, a standard 0 value would be an easy fallback in these situations. However, for such a system to work, the chance of a false-positive must be reduced to be a close to zero as possible. If the system were to begin reporting bad data in cases where no tampering occurred, faith would very quickly be lost in the system and tracking as a whole abandoned. Rigorous testing should occur to ensure that this does not happen.

4.2 Reducing Boat Trips and Maximizing Passenger Counts per Boat

After studying the public transportation system which is used to transport passengers from cruise ships throughout the city of Venice, it was concluded that there was an excessive amount of boat trips being made, many of which were empty. These inefficiencies have been addressed and improved through reorganizing this system and implementing new scheduling techniques, as is discussed below.

4.2.1 Boat Counts Show a Large Number of Unnecessary Trips Being Made

On November 22, 2015, our IQP team performed data collection for the public transportation system. Two members of our group were stationed on the island of Giudecca in order to see the cruise ships and count all public transportation boats going in and out of the cruise ship terminal, while recording their license numbers. These two members then reported this information to two other members, who were stationed near the boat stops on San Marco, where passengers departed these boats. These latter two members then counted the number of passengers who got off any applicable boats. The team arrived at these locations at approximately 7:00am for the 8:30am arrival of the first cruise ship of the Sunday, and stayed stationed until approximately 2:30pm, past when all passengers had disembarked the cruise ships. These locations can be seen in Figure 28: “Cruise Ship Count Area of Study”.

From these counts, there were five total boats recorded that carried passengers. Two of these boats were double decker Marco Polo boats, one of which carried 91 passengers and the other carried 110, all of which departed at San Marco. The other three boats were *Alilaguna Linea Blu* boats, which were determined to be about 90% empty. An exact number was unable to be reached for these boats due to the fact that these boats make multiple stops before the San Marco stop. This means that passengers could have departed these boats before this stop, and other passengers could have embarked them at the stops before San Marco, therefore making passenger counts at San Marco not relevant or able to be counted for these *Alilaguna* boats. Another important piece of data from these counts were the nineteen total empty boats going to and from the cruise ship terminal without carrying any passengers. These empty boats consisted of both double decker boats and *Alilaguna* boats. An info graphic depicting these inefficient boat trips can be seen in Figure 40 below, which shows the nineteen empty boats and three partially filled *Alilaguna* boats.

Figure 40: Empty and Filled Boats Coming from Cruise Ship Terminal

4.2.2 Unnecessary Boat Trips Mean Inefficiency in Public Transportation System

Due to the fact that nineteen of the twenty-four total boats counted were empty, this part of the public transportation system is very inefficient. These trips are contributing to moto ondoso while making unnecessary trips that provide no value to the public transportation system’s transport of passengers. Despite five of the boats carrying passengers, they were inefficient as well. These inefficiencies can be seen in the low utilization rates of the double decker Marco Polo boats, which have a capacity of 315 passengers.[53] With one boat carrying 91 passengers and the other 110, this leaves utilization rates of 29% and 35%, as can be seen in Equation 6 and Equation 7.

$$\frac{315\ passenger\ capacity}{91\ passengers} = 29\%\ utilization$$

Equation 6: Utilization of First Marco Polo Boat

$$\frac{315\ passenger\ capacity}{110\ passenger} = 35\%\ utilization$$

Equation 7: Utilization of Second Marco Polo Boat

Also, the *Alilaguna* boats, which carry 160 passengers, were either empty or approximately 90% empty, which are very poor utilization rates as well.[54] These utilization rates must be increased so that moto ondoso is reduced in the canals.

4.2.3 Increasing the Efficiency of the System with *Alilaguna* Synchronization

Due to the fact that the *Alilaguna* boats are more efficient than the double decker boats in terms of producing *moto ondoso* as will be discussed in the hull improvement section, these are the boats that will be used. More specifically, the *Alilaguna Linea Blu* will be used here, as it is the line that goes from the cruise ship terminal to the Marco Polo airport, as can be seen in Figure 41 below. This line currently goes to the cruise ship terminal once every hour, from 8:56 to 17:56.[55]

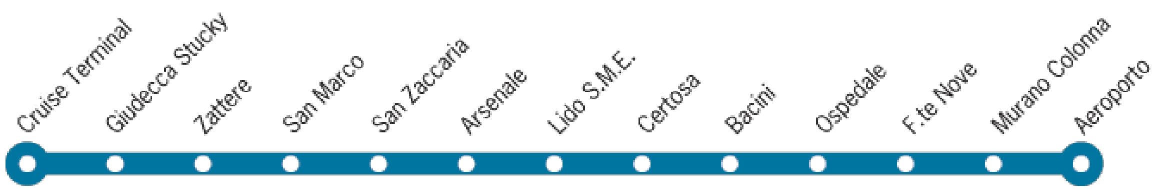

Figure 41: Alilaguna Linea Blu

In order to increase the overall efficiency of the passenger transportation from the cruise ships, the *Alilaguna Linea Blu* schedule will be improved and synchronized with the cruise ship arrivals. This will begin by sending a "burst", or increased amount of boats in a short period of time, of *Alilaguna* boats when cruise ships arrive. More specifically, the *Alilaguna Linea Blu* schedule will be directly synchronized with the times in which the cruise ships unload their passengers, and will send an increased number of boats at these times. Due to the fact that the ships do not begin unloading passengers immediately upon arrival into the terminal, the burst of *Alilaguna* boats will not begin until the appropriate amount of time has passed after the ship

53 (*Marco Polo*)
54 (Imboden)
55 (*Linea Blu*)

arrives. From the data collection on 22/11/2015, it was concluded that it takes approximately one to two hours between the cruise ship's arrival and when passengers begin unloading the ships to embark public transportation boats. Furthermore, it was concluded from the counts that it takes about three hours to fully unload one cruise ship, with these times varying for every cruise ship.

In more specific terms regarding the bursts, during these three hours in which the cruise ship is unloading, there will be an additional *Alilaguna* boat introduced every half an hour. This means that there will be six total *Alilaguna* boats arriving at the cruise ship terminal when a cruise ship arrives, including three boats from the existing schedule which can be seen in Figure 41, and three additional boats introduced every half an hour for three hours. These numbers were chosen because, as previously stated, 25% of the average of 3,553 passengers per cruise ship choose to take boats from the terminal, yielding a total of 889 people as can be seen in the earlier Equation 2. If six *Alilaguna* boats arrive at the terminal for each cruise ship arrival, and each boat has a capacity of 160 passengers, this means that 960 passengers will be able to be transported.[56] This is just enough boats to be able to handle each of the calculated passengers taking boats.

There will also be several other measures taken to further enhance this synchronization. First of all, these bursts of *Alilaguna* boats will be introduced as often as cruise ships arrive, which could mean multiple times per day. This increases efficiency because the bursts are only sent to pick up these passengers when necessary, and are not simply sending extra boats throughout the entire day when they are not needed. It must also be addressed that the cruise ships will not carry the same volume of passengers all year long. The number of passengers per ship will vary based upon the season, and this must be taken into account. Due to these seasonal changes, the *Alilaguna* burst schedule can be reduced in the case of periods of low passenger counts, or increased in the case of periods of high passenger counts. For example, if there are less passengers per ship during the winter months, the number of boats arriving per cruise ship can decrease from six to four or five, or if there are more passengers per ship during the summer months, then the number of boats per ship can increase to seven or eight. The *Alilaguna* schedule can also be adjusted on a shorter-term basis if need be. This is because the cruise ships must confirm at least 24 hours in advance if they are still arriving, or if there is a delay, so the city can be informed.[57] This means that if a ship cancels, *Alilaguna* has 24 hours to then cancel the planned burst of boats, therefore eliminating any unnecessary *moto ondoso* that would be created without the ship arriving. Likewise, the burst of boats could be adjusted based on if there is a delay for the cruise ship arriving.

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[56] (Imboden)

[57] (Bellingham et al. 2010)

4.2.4 Number of Boat Trips Reduced and Passengers per Boat Increased

The implementation of this new *Alilaguna Linea Blu* schedule will result in a reduction in the overall number of boat trips made to the cruise ship terminal. This is due to the effective allocation of *Alilaguna* boats, with which there will be no further need for other double decker boats, tour boats, or any other boats to visit the terminal looking for passengers. This is crucial because it will reduce the number of empty boat trips, as these boats will not visit the terminal to look for passengers and come out empty. Compared to these double decker boats, *Alilaguna* boats are much lighter and displace much less water, therefore producing much less *moto ondoso*, as will be discussed below in the section regarding hull improvements. This means that a system involving *Alilaguna* boats is much more efficient.

To show the decrease in boat trips, consider if one cruise ship arrives in one day, which will mean twelve total trips with the new schedule. This is due to the fact that there were previously nine trips made by the existing *Alilaguna* schedule in Figure 41, which will now increase by three if one burst is needed for the one ship arrival. If two cruise ships arrive in one day, this will mean nine trips plus six additional boats from two bursts needed, totaling fifteen boats. If three cruise ships arrive in one day, this will mean eighteen total boats, or if there are four cruise ships arriving, this will mean twenty-one total boats, all by the same logic. This shows that even if four cruise ships arrive in one day, there will still be less boat trips made than when twenty-four boats were counted during this project's data collection on a day when two ships arrived. Along with increasing the efficiency of the passenger transport system, less boat trips means that the amount of *moto ondoso* produced has decreased.

On top of this, these boats will be transporting even more passengers than before when there were more trips made due to the fact that the number of empty trips has decreased. The passengers will be incentivized to take these boats because they will be arriving more frequently than before when the *Alilaguna* boats arrived once per hour. This will ensure that the boats are filled more, therefore further reducing the number of empty boat trips and increasing the overall efficiency of the system. Due to the increased number of passengers per boat, the overall *moto ondoso* will be further reduced.

4.3 Taxi Transportation System

On 1 December 2015, we conducted a pilot interview to get a general sense of the tourists' attitude towards ride sharing for taxis and to refine our survey questions. Figures for the San Marco surveys can be found in Appendix D. In our pilot interview, we obtained a sample size of 40 people at Piazza San Marco. After the interviews, it was found that 26 of tourists expressed interest in using a taxi-sharing system, while 14 were not interested. Those who were interested were asked further questions while the interview concluded for those who did not express interest in sharing. When interviewed, 12 people desired at least a 20 euro discount, while 10 desired a 10 euro discount. The average amount of time people were willing to wait for a 20% discount was 16 minutes. The average amount of time people were willing to wait for a 40% discount was 29 minutes.

After analyzing this data, we determined that a restructured set of questions would be needed for following interviews. We determined that the questions regarding ride-sharing interest was not valid and removed it. Questions regarding the tourists' length of stay and luggage were needed to predict how worthwhile taxis would be for tourists. We also added questions asking what kinds of transportation the tourists have used in Venice and asking why did those who only took ACTV and *Alilaguna* boats did not take taxis. Lastly, we slightly modified the questions regarding ride-sharing preferences.

On 7 December 2015, we conducted surveys with 23 people at the Marco Polo Airport. Figures for the Marco Polo surveys can be found in Appendix E. All interviewed were tourists, and 15 had brought luggage with them. All of the tourists were "overnighters" and their planned stays averaged 4 days. None of tourists were staying only 1 day, most likely because they flew in and stayed overnight rather than flying in and out of the city on the same day. They also used various forms of transportation throughout their trips: primarily ACTV and *Alilaguna* boats. Of the 16 who did not use the taxis, 6 said they had/would consider using the taxi service. When we asked those who had not considered using a taxi, the most common reason was because they found it to be too expensive; other reasons include that they did not know how to use it and that they did not know about it. The majority of tourists would have accepted a 30% discount when listing amounts starting at 10%, increasing increments of 10%, ending at 30%. It was also found that 15 people were willing to wait 20 minutes for a 30% discount.

After determining that the total number of people interviewed was insufficient, we conducted more interviews at Piazza San Marco again on 12 December 2015. The figures of this round of surveys can be found in 0. A total of 35 people were interviewed, all of whom were tourists; 19 were "overnighters" and 16 were day trippers. This round of surveys had day trippers most likely because those who take a plan to Venice probably plan to stay overnight, while interviewing at Piazza San Marco offered a more varied group of tourists. The tourists at Piazza San Marco stayed for an average of 2 days. This group of tourists primarily used the *Alilaguna* and ACTV boats, although 7 had used taxis. Of the 28 who said they never rode in a taxi, only 6 said that they would consider riding in them. Once again, the main reason why people did not consider using taxis is they found them to be too expensive. The majority of tourists desired at least a 30% discount for them to share a taxi. When asked about the maximum amount of time they would be willing to wait to reach their destination, 14 tourists said they would wait 10 minutes while 13 said they would wait 20 minutes.

Since most tourists stay overnight and over half bring luggage, taxis will continue to be beneficial to them. The taxis are vastly underused in comparison to the ACTV and *Alilaguna* boats; the most common reason that tourists expressed for not using taxis is because they thought it was too expensive. Taxi sharing would have a great chance of success since it would be cheaper for all the tourists who originally would not consider taking a taxi. The ride-sharing preferences the tourists expressed also show that they are willing to share a taxi and wait to reach their destination if the desired rate reduction is given.

4.4 Boat Hulls and Design

The four aspects that we intended to change for the three hull designs were at the bow, the chine, the keel and the weight due to structure change, as described in the previous chapter. They were implemented in the same fashion for all the boat types we worked with. In what follows, we present before and after pictures of the current boat hulls and our newly designed hulls. These boats now have better penetration at the bow, and the water will flow around them more effectively. As planned, the chine is visibly more round and the keels are now angled, which will help reduce *moto ondoso*. Weight reduction was suggested by changing the hulls from single skin structure to sandwich structure which reduced the weight by approximately 20-30%. These changes are described further in the methodology section. The best option to reduce weight would be to switch to carbon fiber because it weighs 70% less than steel; however, this material is very expensive and will be discussed further in the recommendation chapter. The next three sections show these changes and the results we gathered.

4.4.1 New and Old Taxi Designs

After inputting the parameters of the current taxi boat and new taxi hull design into Maxsurf, as shown in Appendix G and Appendix I, we were given graphs that represented the amount of resistance the two boats faced at certain speeds, at the same weight. These charts can be seen in Appendix H and Appendix J. Then we took the same hulls and reran them through Maxsurf at a lighter weight, due to our structure change. The data for this can be seen in Appendix K and Appendix M with the resulting resistance graphs in Appendix L and Appendix N . Since the boats are only allowed to travel at a maximum of 20 km/hr within the lagoon, we looked at the resistance values at this speed. Table 3 shows the comparison of switching from the old hull to new hull, or switching from single skin to sandwich. If you use the old design, but switch to a sandwich material and reduce the weight, there is 10% increase in efficiency. If you use the new design, but at the same heavy weight, there is a 19% increase in efficiency. When you switch to the new hull and the new lighter weight, there is an overall efficiency increase of about 29%. This 29% increase in efficiency does not mean there will be a 29% decrease in wake production. The only way to get the exact amount of wake produced, as stated before, would be to build a physical model of the boat, and test it in a tank of water. Maxsurf gives us the total resistance, not the components of it (skin friction and wave resistance). Even though this is true, we do know that a greater efficiency means less waves so we can say with confidence that our boat designs decrease wake production.

Table 3: Resistance Values for Taxi Hull

KN @ 20 km/hr	Actual Hull	New Hull
Actual Weight	**2.1**	1.7
Lighter Weight	2	**1.5**
Difference	0.6	KN
Improved Efficiency		**29%**

Figure 42 is the 3D model we produced for the replica of the current taxi boat. Figure 43 is our new design, as can be seen the chine is now round, and the keel is angled.

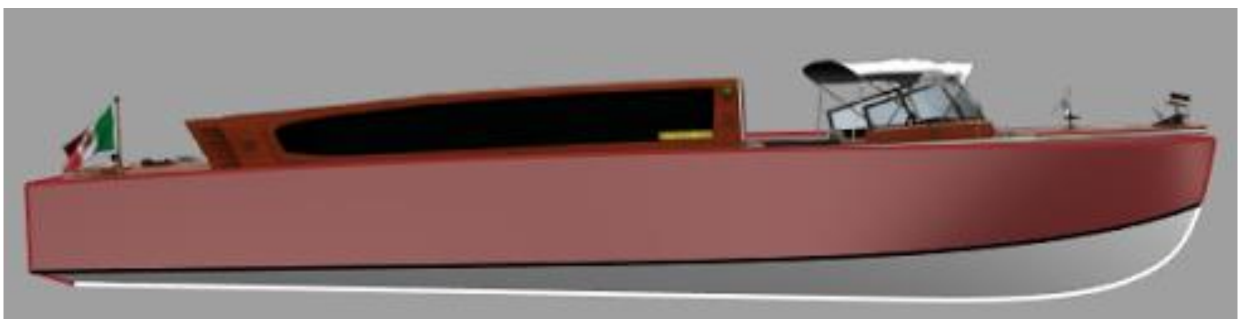

Figure 42: Current Design of Taxi Boat

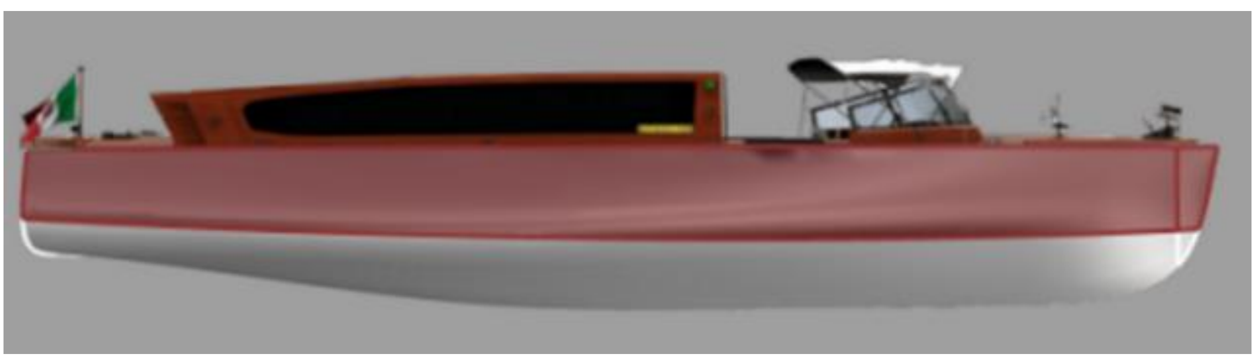

Figure 43: New Design of Taxi Boat

Figure 44 is a side-by-side aerial comparison of the current taxi hull with our new taxi. As can be seen in this view, there is better water penetration at the bow. For better viewing of the old and new designs, Appendix O and Appendix P shows the four-sided view of both of these boats.

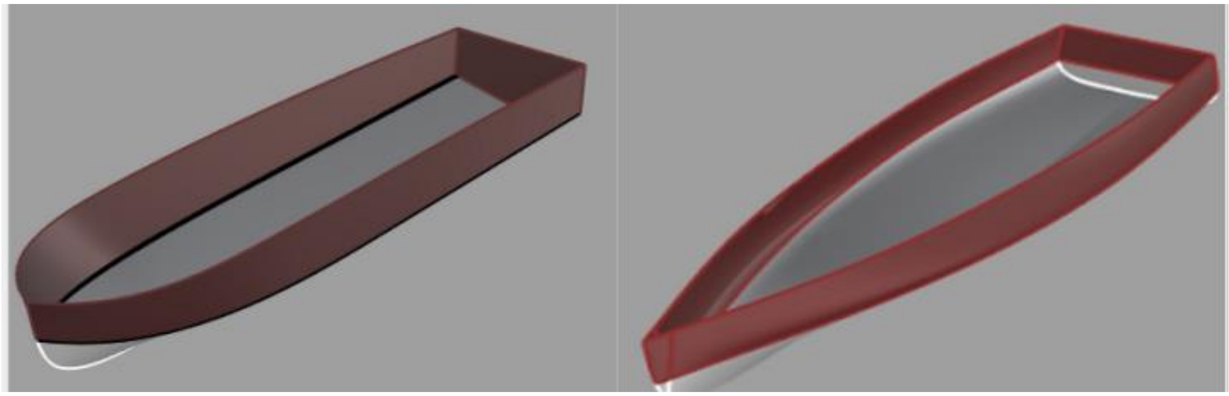

Figure 44 Side-by-Side View of Current (left) vs. New (right) Taxi Boat

4.4.2 New and Old *Alilaguna* Designs

Since we changed the same four parameters on each boat type, we would expect the same increase in efficiency in all hull designs. No matter the boat style, the results will be similar. We know the steps to achieve this efficiency so they can be adopted on any design because they will not change. Figure 45 shows the current *Alilaguna* that we modeled and Figure 46 shows our new hull. As can be seen, the chine is now round and the keel is angled better, in the same fashion as it was for the taxi hulls.

Figure 45: Current Design of Alilaguna

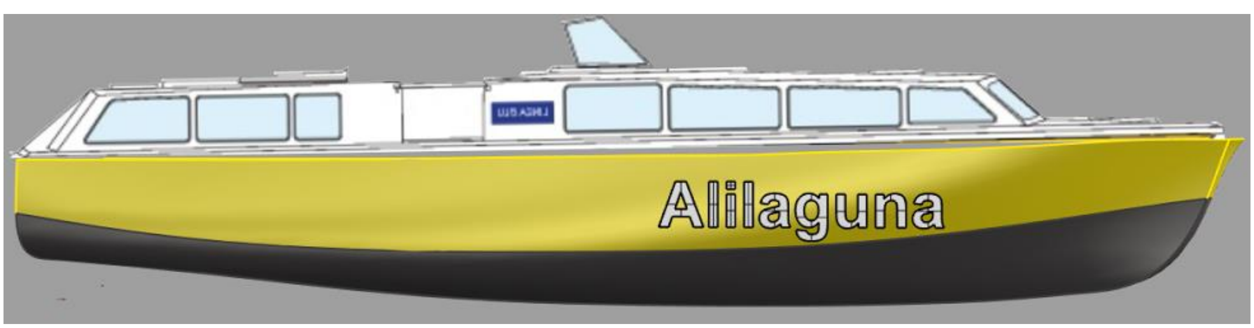

Figure 46: New Design of Alilaguna

Figure 47 shows the aerial view of the two boats side-by-side, and in this view it can be seen that there is now better penetration at the bow. Since we changed these three aspects, as well as the weight, we can predict that the efficiency of the *Alilaguna* will be increased by approximately 29% due to shape and structure change. For better viewing of the old and new designs, Appendix Q and Appendix R show the four-sided views of both of these boats.

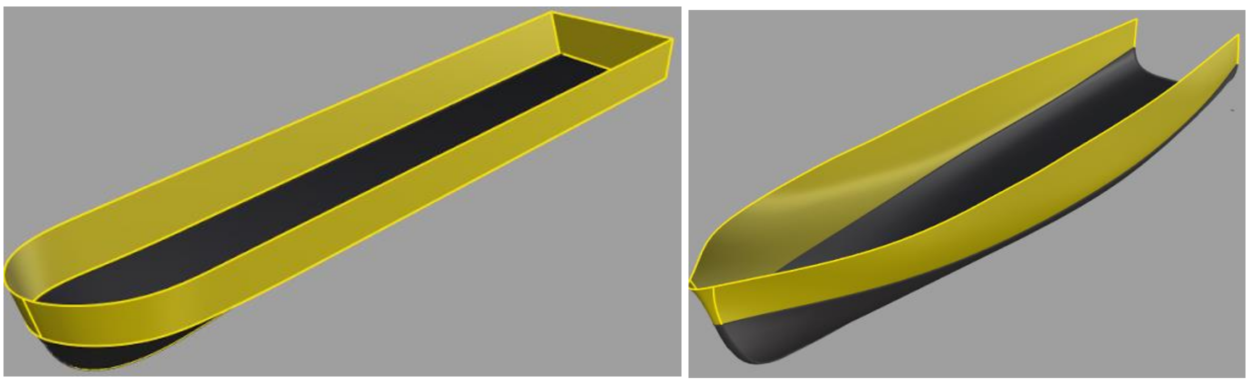

Figure 47: Side by Side View of Current (left) vs. New (right) Alilaguna

4.4.3 New and Old Cargo Designs

Once again, the same four aspects were changed for the cargo boat, the bow, the chine, the keel and the weight. Since we changed the same four parameters, we would once again expect the same increase in efficiency in the cargo boat. Figure 48 shows the current cargo boat that we modeled and Figure 48 Current Design of Cargo BoatFigure 46shows our new hull. As can be seen, the chine is now round and the keel is angled better, in the same fashion as it was for the taxi and *Alilaguna* hulls.

Figure 48 Current Design of Cargo Boat

Figure 49 New Design of Cargo Boat

Figure 50 shows the aerial view of the two boats side-by-side, and in this view it can be seen that there is now better penetration at the bow. Since we changed these three aspects, as well as the weight, we can predict that the efficiency of the cargo boat will be increased by approximately 29% due to shape and structure change. For better viewing of the old and new designs, Appendix S and Appendix T show the four-sided views of both of these boats.

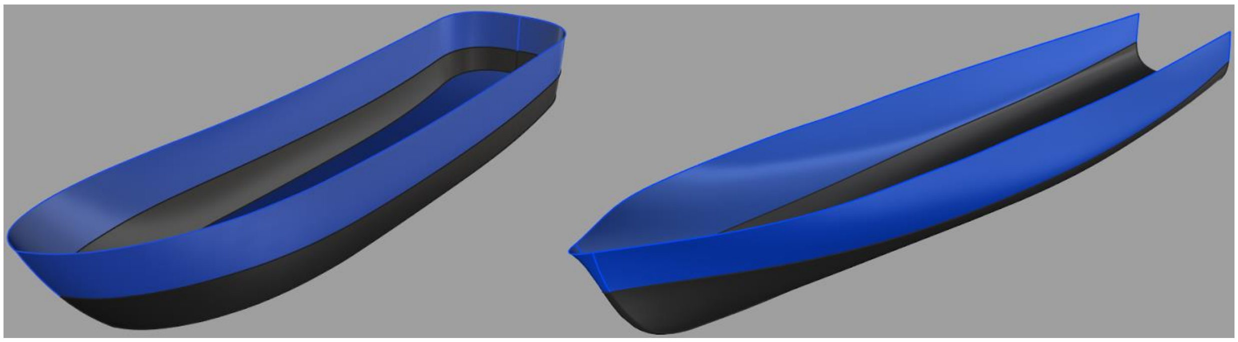

Figure 50 Side by Side View of Current (left) vs. New (right) Cargo Boat

4.4.4 Analysis of Four Criteria for Improving Boat Hulls

Before designing our new hulls there were several aspects that we had to take into consideration first, as mentioned in the methodology chapter. These restrictions were all thoroughly looked at and our goals were met. As was shown in the above sections, the design of the cargo, taxi and *Alilaguna* hulls have not changed drastically. The most noticeable differences lie underwater, where nobody would be able to see the slight changes. The keel is directly underneath the water, the chine is at the surface and most of the bow is underwater. This preserves the historical design of the boats and unlike in previous redesigning efforts, Venetian citizens would be more willing to accept these designs. Also, since these designs were developed with the help of a local Venetian and with Venetian culture in mind, instead of using third party designer, there will hopefully be less aversion to our designs. The total weight of the boats is decreased by 20-30% due to the change from single skin structure to sandwich structure. This estimate was taken from our collaborator, Gregorio Giorgetti, and essentially means that instead of having one thick layer of material, there are two smaller layers of material with a lightweight core in-between them. There is a range for this reduction because it depends on what type of material is used to build the boat hull. This change in structure would also lead to less horsepower being used to drive the boat, making the boat more efficient. Due to this switch from single skin to sandwich layering, the total prices of the boat will be increased by about 10-15% according to estimates taken from an experienced boat designer. In the grand scheme, this is not a large increase because the new hulls would create less wake, which means the city would have to pay less on canal repairs. The increased boat cost would also be offset by lower maintenance costs of the new hull designs. Our final consideration was the wake production of the boats. Since we know the overall efficiency of these boats increased, we know that the wake decreased, but we are not capable of calculating the exact amount without building exact models of the boats. These four criteria were met for all three of our new boat hulls, so our designs are successful.

4.4.5 Implementing the M Hull for the *Vaporetti*

After extensive research into the *vaporetti,* we have determined that the shape of the hull is actually very efficient. While we observed these boats passing through the water, we noticed that they created minimal to no waves. This was quite astonishing, however when we observed the boats that were near the *vaporetti,* they would be knocked around in the water quite immensely. This is due to the fact that these boats displace vast amounts of water. The only thing we could to do reduce this effect was to reduce the weight of the boat. The best option is to switch to carbon fiber, as previously stated, but fiberglass is the cheaper option. Taking this into account and our previous research on the M-Hull, we concluded that the best option for this boat type is the M-Hull. It is the most efficient hull design by far. The upfront cost of the boat is high because first a mold must be created, but after several boats have been made the cost will go down. These hulls can be mass-produced once a mold is created, which is why they are perfect for the *vaporetti* considering there are many of them in the canals, and they are all the same design. The M-Hull is not as feasible for taxi boats or cargo boats because they are privately owned. This means that unless a buyer would want the same design as everyone else, they would have to pay for the mold as well, which is expensive. The feasibility of creating this boat design will be discussed in the recommendations chapter.

4.5 The Five Year Plan

Based on our results, a five-year plan was developed to reduce the *moto ondoso* in the canals. This five-year plan can be found in Appendix U**.** The first year focuses on immediate improvements and setting up for future reductions. Namely, it includes improvements in speed limit enforcement and taxi sharing. The second year completes the introduction of the taxi-sharing and cargo tracking systems, and would have the new boat hulls modeled and tested. The third year would begin advertising and incentivizing the new boat hulls amongst cargo and taxi transporters. The fourth year introduces the latest generation of *Alilaguna* boat hulls. Finally, the fifth year is primarily an assessment year to see if the reductions expected occurred.

5. Conclusion and Recommendations

In this chapter, we will summarize our results for each of our four objectives, as well as presenting our recommendations for further studies and implementations of our solutions.

5.1 Cargo Transportation System

We conclude that an efficiency incentive system could be used to promote the re-engineering of Venice's cargo delivery system. Such a system was developed, and encouraged the use of by-location deliveries by creating regulations which would restrict cargo boat movements throughout Venice that would be unachievable in a by-product delivery system. It also included a stipulation for reduced speed, as cargo boats are notorious for travelling above the speed limit. A tracking system was developed which could be used to ascertain how many of these boats followed the regulations and how many didn't. Additionally, a 2013 study which organized Venice into 42 delivery zones was reviewed and an estimate of the number of both standard and refrigerated cargo boats necessary for each zone was made, in order for the cargo consortiums to be able to easily organize which boats go where. These individual boat restrictions, along with the number of boats assigned to each zone, were combined into a series of equations which determined what percentage of boats and zones followed the regulations.

To create an incentive, the *Interscambio Merci* was used. This building, built over a decade ago to help re-organize the cargo delivery system, is, as of the end of 2015, currently undergoing a bidding process for a cargo consortium to take control of it. The rent would be set at €500,000 per year, and was used as an incentive. A maximum rent reduction of €99,000 per year was set, translating to a potential savings of up to €8,250 per month. This value represents a maximum amount of savings per month, but it was combined with the efficiency equations to create a sliding range of discount, dependent on how efficient the delivery system was for that particular month. An important item to note is that this system is entirely beneficial, not punitive. Assuming the cargo boat operators continued to operate inefficiently ignoring the guidelines, no operator would incur a loss, monetary or otherwise. The only change happens if they do opt to increase their efficiency and follow guidelines, in the form of reduction of yearly rent.

This reduction would be dependent on the tracking system used to determine quantitatively how efficient the system was. These quantitative values were determined to be the number of zones boats stopped in, what speed they travelled, and how many boats went to each zone. A GPS module built by *Eraclit* was used to see if it would be viable as a tracking system. It was concluded that the position points combined with a timestamp could easily be used to compute these values, as speed could be determined along with stops made along a cargo boat route.

5.1.1 Recommendations for Determining Boats per Zone

In its current iteration, the number of boats allotted per zone is a static value but should be modified to be much more dynamic. It was determined by counting the number of each types of stores on each island, and then combining that number with the average number of packages such stores receive. Although such an analysis could be performed each year to determine the number of cargo boats per zone for that year, a better system would have the values be updated on a daily basis. This is especially true since past studies have perform cargo volume analysis only in the context of the season during which they were in Venice; cargo volume could be expected to change from season to season especially with the varying levels of tourists.

This dynamic boat allocation could be done with the use of the *Interscambio Merci*. Once the warehouse has been put to use, the cargo consortium controlling it will know exactly how many packages and where those packages are going on a daily basis. They could achieve this by scanning and entering which island each package is going to for the day into a computer program. The program would then use this information combined with the average storage capacity of standard and refrigerated boats in order to provide an accurate estimate of the number of boats required per island for the day. This would provide a much more accurate view of the number of boats required, and would in turn translate to a more accurate warehouse rent reduction.

5.1.2 Recommendations for Tracking Efficiency

Although a GPS module was used as a potential efficiency tracker during this study, other systems should be researched. These systems may be simpler, less expensive, or more convenient for the cargo boat drivers. Currently, the GPS system would require each boat to be fitted with a relatively expensive GPS module, and for this data to then be taken from each individual boat and uploaded to a server for processing, each day. The processing itself is non-trivial, as it needs to parse and filter all GPS data points for the day, eliminate bad data, and then extrapolate speed and stops based on timestamps. Several alternate systems should be researched.

One such system, also built by *Eraclit*, is based on electronic “gates”. In such a system, each boat would be equipped with an emitter, and when the emitter passes near a receiver the emitter ID is recorded along with a timestamp. These receivers could be placed at each cargo delivery dock, and tuned such that only a cargo boat stopping at the location sets off the emitter, not every boat which passes by. This would eliminate the processing of data to determine stop information, however it would also be incapable of determining continuous boat speed. Speed tracking would have to be implemented separately, and independent of these trackers and receivers.

5.1.3 Recommendations for Determining Feasibility with Cargo Operators

Before any tracking or efficiency incentive system could be put in place, cargo operators should first be surveyed. These surveys would have to cover two different aspects of the cargo re-engineering system. First, do operators individually believe that the cargo system needs an overhaul and that efficiency could be increased. This party of the survey would cover to what extent cargo transporters are aware of inefficiencies of the system and of how much *moto ondoso* they produce. It would also determine whether they believe the current delivery scheme should be changed, and if so, how it should be changed. The second part of the survey would cover the proposed changes and incentive system, to see how well it would be accepted. This would determine if cargo transporters are willing to let themselves be tracked, but should also emphasize the primary advantages of the system, specifically that it is entirely beneficial and not punitive. It would essentially determine if the proposed tracking and incentive system would be a welcome addition to the cargo transporters.

5.2 Public Transportation System

After performing counts of boats going to and from cruise ships docked in Venice, along with passengers departing these boats, it can be concluded that this system is currently inefficient and produces large amounts of unnecessary *moto ondoso*. This inefficiency stems from the large amount of empty boat trips being made, as this project counted nineteen empty boat trips in just one day. Furthermore, the boats carrying passengers were not full, nor were they utilized sufficiently. This can be shown as the two double decker boats observed were 71% and 65% empty, while the three *Alilaguna* boats observed were approximately 90% empty, with an exact number unable to be reached for aforementioned reasons.

These inefficiencies can be reduced along with the amount of *moto ondoso* produced through improvements in the *Alilaguna Linea Blu* schedule and through synchronizations of this schedule with the arrival of the cruise ships in Venice. This will be accomplished by sending bursts of *Alilaguna* boats each time a cruise ship arrives. These bursts, consisting of three extra boats going to the terminal, will make it possible to transport more passengers from the cruise ships more efficiently. These boats, along with the boats from the existing schedule, will be able to handle the 889 passengers calculated from past averages and from the 2010 study stating that 25% of passengers take boats from these ships.[58] This is more efficient because this will reduce the number of empty boat trips being made to and from the terminal, while eliminating the need for other boat types, including the double decker boats. The boats will be fully synchronized to arrive when the cruise ships begin unloading passengers, therefore providing

[58] (Bellingham et al. 2010)

boats exactly when needed and eliminating any boats from simply going into the terminal to look for passengers. This system will be further synchronized by accounting for multiple ships per day, different passenger count numbers for different seasons, and by adjusting in advance based on updates about cruise ship cancellations or delays.

This system will eliminate unnecessary boat trips and will therefore make the overall public transportation system from the cruise ships more efficient while reducing *moto ondoso*. Less boat trips will be required, and the boats will be filled with more passengers due to the increased incentive of the *Alilaguna* boats coming every half an hour during unloading times as opposed to the previous hourly basis.

5.2.1 Recommendations

The first action that is recommended to continue these efforts is to collect more data about boat counts coming from cruise ships that dock in Venice. These counts should include the number of boats going to and from the terminal when a cruise ship docks, the number of these boats that are empty, the number of these boats that carry passengers, and how many passengers are on those boats. This increase in data collection will provide larger sample sizes from which solutions can be developed with the maximum accuracy possible.

The next plan of action will be to contact *Alilaguna* and cruise ship officials directly to see the feasibility of this solution. *Alilaguna* drivers should also be contacted in order to record how many passengers the boats usually carry when coming from cruise ships, along with providing feedback on the proposed solution. From this, the necessary steps that will need to be taken in order to carry out this solution can be determined, with increased accuracy from contacting *Alilaguna* drivers directly. It is important to mention to *Alilaguna* that the use of bursts will bring them increased revenue, therefore providing them the incentive to use this solution.

From here, the solution should be tested to determine its effectiveness. This will be done by choosing a time period in which several cruise ships will be arriving, and then testing the improved and synchronized schedule with these ships. After testing is complete, the results will show whether the solution is effective or not. This will be based on how efficiently the passenger transport system performs, whether or not empty trips are reduced, and whether or not the boats are filled with passengers. It will then be determined if the solution is ready to implement, or if changes will have to be made.

Once the solution is ready, it will then be introduced by updating the *Alilaguna Linea Blu* schedule to include all changes being made. It will be equally important to perform all necessary steps to synchronize the cruise ship companies with *Alilaguna*, as stated above. Once this is done, the final step will be to advertise these changes to all cruise ship passengers so that the new system can be fully implemented and utilized.

5.3 Taxi Transportation System

After analyzing the surveys, we determined that a ride sharing option in the taxi system is feasible. Of the tourists we interviewed, only a very small amount have actually taken a taxi. Most of those interviewed who did not taxis would not consider taking a taxi, primarily because they thought it was too expensive. Having a ride-sharing program could be beneficial to both the drivers and their customers: their drivers would have a new client base of people who thought taxis were too expensive and the customers can have the privacy and convenience of a taxi at lower, more affordable prices. When people split rates in a shared taxi, they can each receive a rate reduction and the driver will still make a profit similar to that of an individual party's. Taxi sharing can help reduce the amount of *moto ondoso* produced because it increases the amount of people on one trip so drivers will not have to take as many. A reduction in rate should be substantial enough to persuade tourists into sharing with another party but small enough so that the taxi drivers do not lose a large amount of profit and so the number of trips of taxis overall does not increase, thus increasing the amount of *moto ondoso*.

Future projects should interview different populations around the city of Venice. More tourist interviews should be conducted to further establish that there is interest in taxi sharing among the people who fuel Venice's most profitable industry: tourism. Interviews with permanent residents in the city should also be conducted to inform them of a cheaper taxi alternative and to gauge their interest. Due to time constraints, we were unable to interview taxi drivers to receive their feedback after analyzing the results of the tourist interviews, so future projects should conduct these after obtaining results from both tourist and local interviews. They should also ask the drivers if they perceive any inefficiencies within the taxi system and their ideas of how the city can better address them.

5.4 Boat Hulls and Design

Since we were unable to test all of our boats in Maxsurf due to time constraints, we had to make some assumptions on overall efficiency improvements. We know that overall efficiency was improved by 29% due to shape and weight change to the taxi hull. The values that we got from Maxsurf were only the overall resistance values. Because of this, we cannot precisely determine the reduction in *moto ondoso,* because it is only one component of total resistance, however we do know that it decreased proportional to increase

Due to this, we recommend that a future project take our designs and run them all through Maxsurf again. Slight adjustments can then be made to the boats in order to create the highest efficiency. To determine the wake reduction, we propose that after the boat hulls are tweaked, a future study build scaled down models of our designs. They should then be tested in a towing tank in order to calculate the wake production. A further in-depth study should be done on the materials of the boat hulls, since weight plays a major factor into wake production. Our preliminary investigations showed that using carbon fiber would be the optimal material, however it is considerably more expensive than steel, and therefore it would be beneficial to study whether or not this price increase would be feasible for the city. This will be a potentially lengthy process, but if the designs show vast improvement, then life size versions should be built and implemented. The easiest boat hulls to implement will be the cargo and taxi boats. This is because they are mostly privately owned, which means that it will take less convincing for individuals to buy these new designs. The idea is that there will be incentives for drivers to purchase our new boat hulls. Since the new hulls create less *moto ondoso*, the buyers may receive a discount on the total cost of the boat, or a tax break. It would work the same way as when citizens in the United States can earn tax breaks if they purchase an eco-friendly car. Implementing the *Alilaguna* designs will potentially be a lengthier process. This is because the entire company would need to be convinced of the efficiencies of our new designs, not just individuals. Future projects could contact this company in order to convince them to buy new hulls for their fleet. In conclusion, more studies should be taken on our boat hulls, as well as meetings with the city to see if we can incentivize people to buy our new designs.

5.4.1 The M-Hull

For larger boats, the M-Hull is still the most efficient design ever proposed. Because of this, we recommend that all *vaporetti* be switched over to the M-Hull design. It is not ideal for privately owned boats such as taxis or cargo boats because they will be more expensive due to the initial investment of creating a mold. An investigation should be taken to find out the difference in cost between carbon fiber and fiberglass. Carbon fiber is the lightest material, 70% lighter than steel, however it is considerably more expensive, therefore fiberglass may be the better option. The M-Hull will be a long term solution for the city because it may take a considerable amount of time to convince ACTV to buy them. We recommend that future projects contact the M-Hull company to design a new boat for the city of Venice, and work with the ACTV company for implementation. Also, further investigation may be done by interviewing ACTV officials to figure out if there is another reason why the M-Hull delivered to the city was never used, and why the project was dropped.

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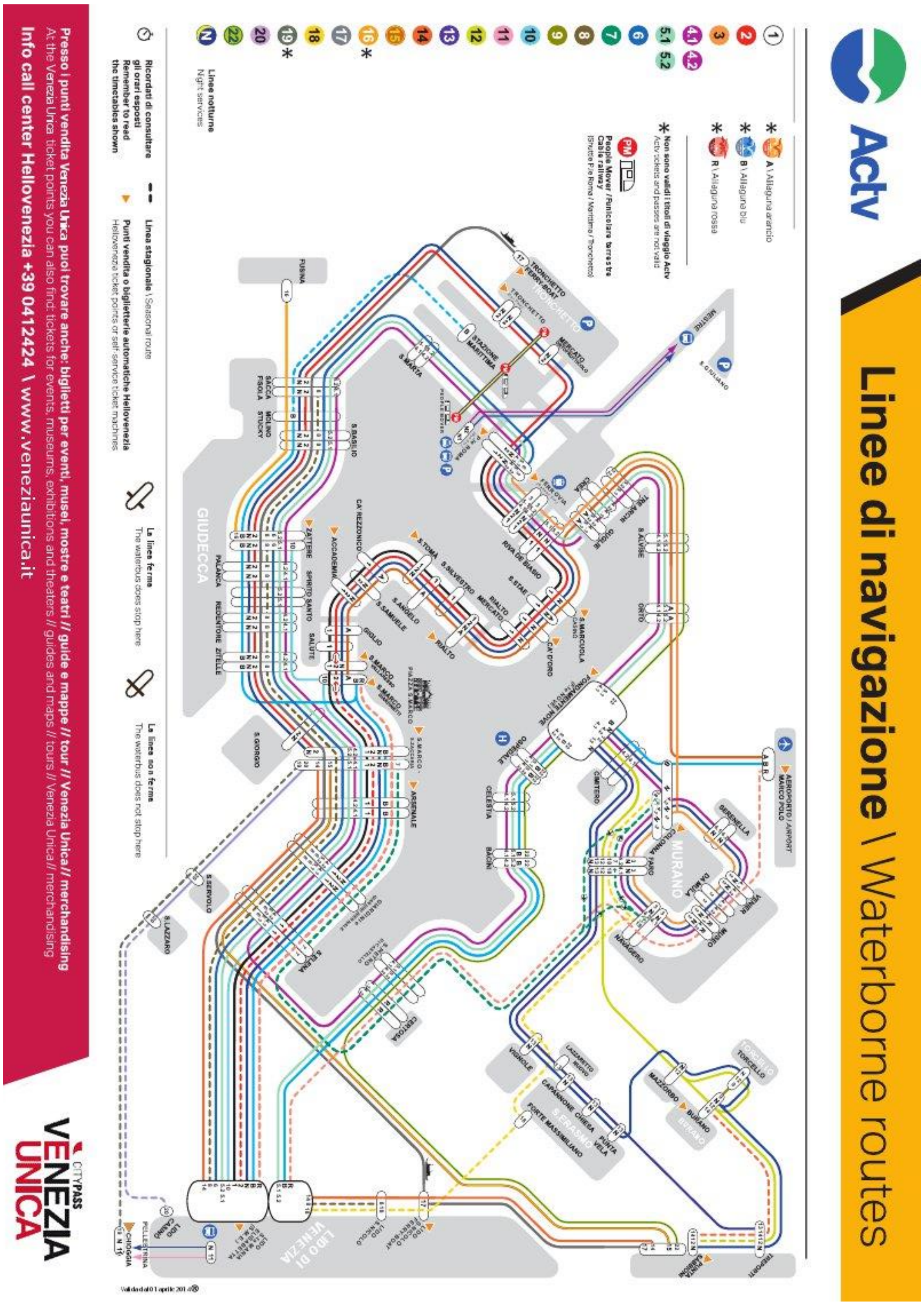
Appendix A. **ACTV Public Transportation Routes**



Appendix B. **Taxi Survey Questions: Version 1**

Tourists often use private water taxis in Venice when travelling to and from the airport, which costs an average of 70 euro. The current taxi system takes one party at a time. Through ride-sharing, customers will share the taxi with another group, pay a reduced rate, and be dropped off in an area common to their destination. Ride-sharing will thus reduce the prices of taking a taxi and the amount of traffic within the canals that the taxi system contributes.

1. Would you be interested in ride-sharing with another group of people?
2. Would you share a taxi with other people if you received a 10% discount? A 20% discount? A 30% discount? A 40% discount?
3. If you were to receive a 20% discount, what is the longest amount of time you would be willing to wait for another group to join yours and travel to a common location close to your destination? 10 20 30 40 50 60 (minutes)
4. If you were to receive a 40% discount, what is the longest amount of time you would be willing to wait for another group to join yours and travel to a common location close to your destination? 10 20 30 40 50 60 (minutes)

Appendix C. **Taxi Survey Version 2**

We are engineering students working with the city of Venice working to increase the efficiency of the public transportation system. Would you mind if we asked you nine questions? It will take less than five minutes of your time.

1. Are you a tourist?
2. How long is/was your stay?
3. Do you have luggage
4. What kind of transportation have you used in Venice?
5. (If they did not take a taxi) Did you consider taking a taxi at any point?
    a. Why not/Why didn't you?

The average taxi ride costs 70-100 euro and they typically take one party at a time. Drivers also charge customers extra for having luggage. We are looking for ways to reduce taxi fares through a ride-sharing program, in which customers would share a taxi with another group of people, pay a reduced rate, and are delivered at their destination.

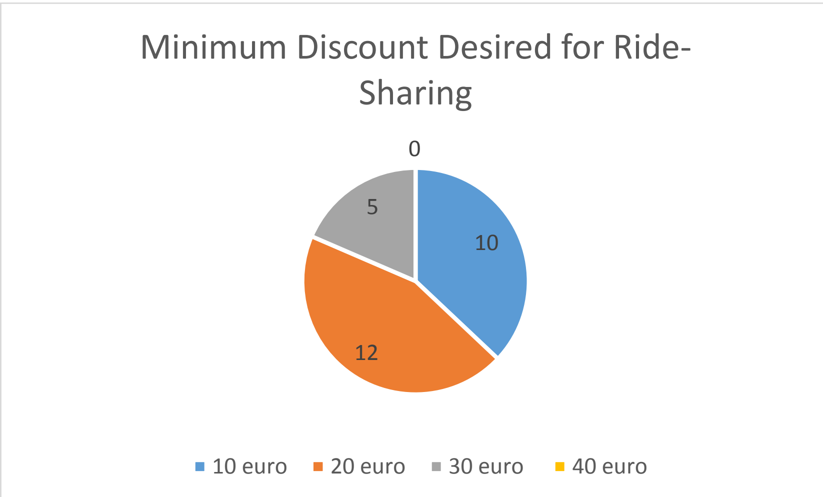
6. Would you share your taxi with other tourists if you received a 10% discount? A 20%? A 30%? (Stop listing at first yes)
7. If you were to receive a 30% discount, what is the longest you would be willing to wait to join another party interested in sharing a taxi? (minutes)

Appendix D. **Piazza San Marco Taxi Survey 1 Figures**

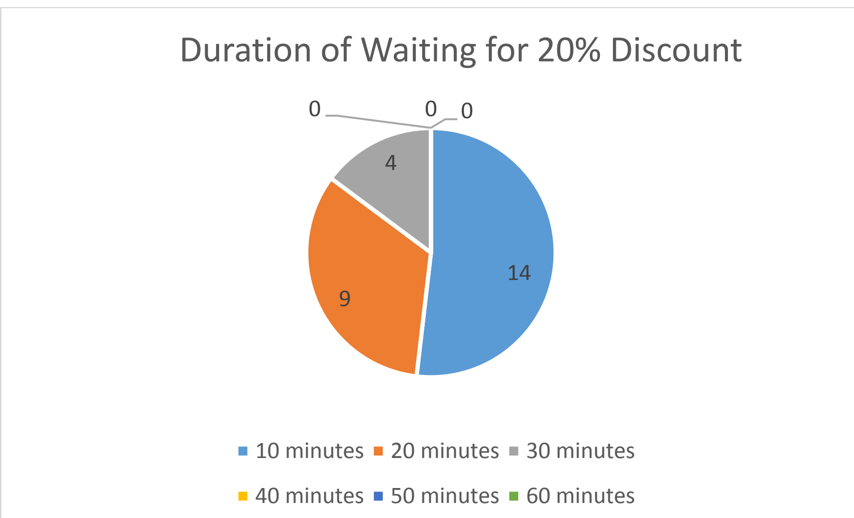
1. Would you consider sharing a taxi with another group of people?

Interest	Interested	Not Interested
Number of People	26	14

2. Would you share a taxi with other people if you received a 10% discount? A 20% discount? A 30% discount? A 40% discount?



3. If you were to receive a 20% discount, what is the longest amount of time you would be willing to wait for another group to join yours and travel to a common location close to your destination? 10 20 30 40 50 60 (minutes)



4. If you were to receive a 40% discount, what is the longest amount of time you would be willing to wait for another group to join yours and travel to a common location close to your destination? 10 20 30 40 50 60 (minutes)

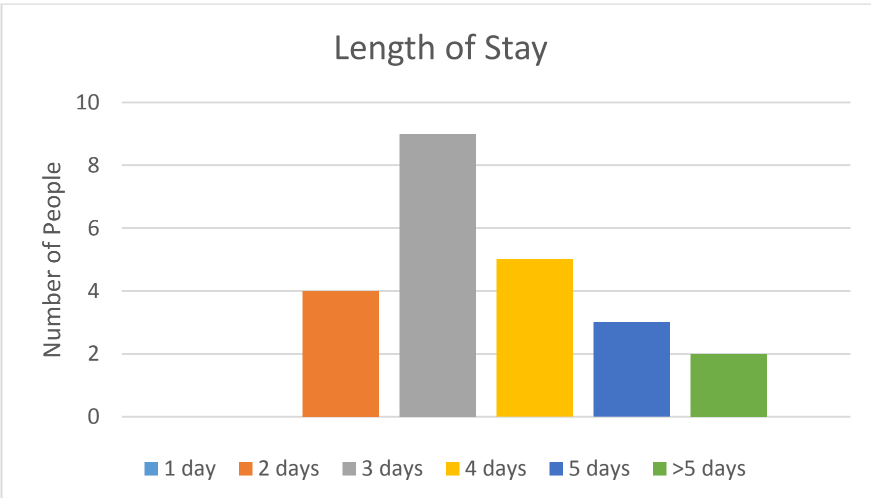

Number of People Willing to Wait for 40% Discount
0
1
3
5
5
13
10 minutes
20 minutes
30 minutes
40 minutes
50 minutes
60 minutes

Appendix E. **Marco Polo Airport Taxi Survey Figures**

1. Are you a tourist?

Yes	No
23	0

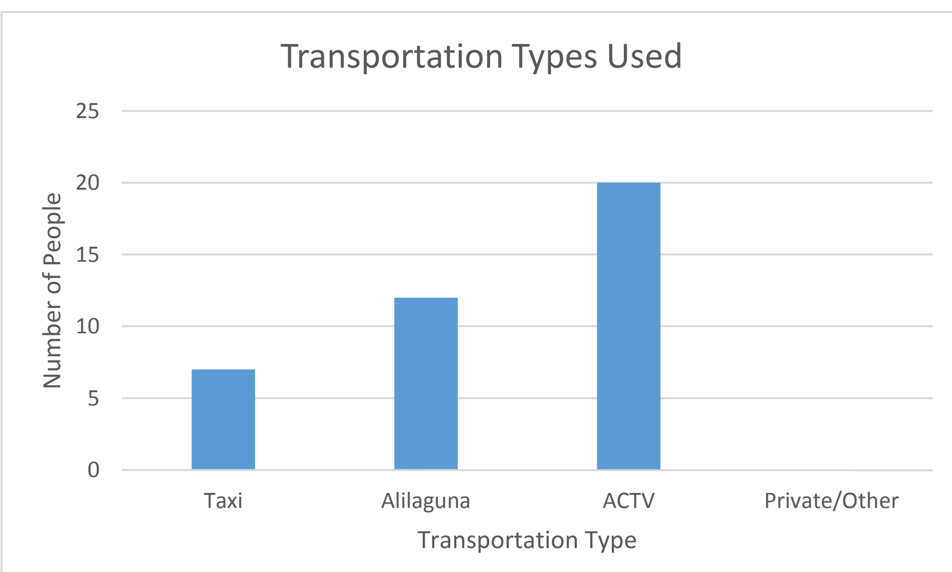
2. How long is/was your stay?



3. (Check to see if they have luggage)

Yes	No
17	6

4. What kinds of transportation have you used in Venice?



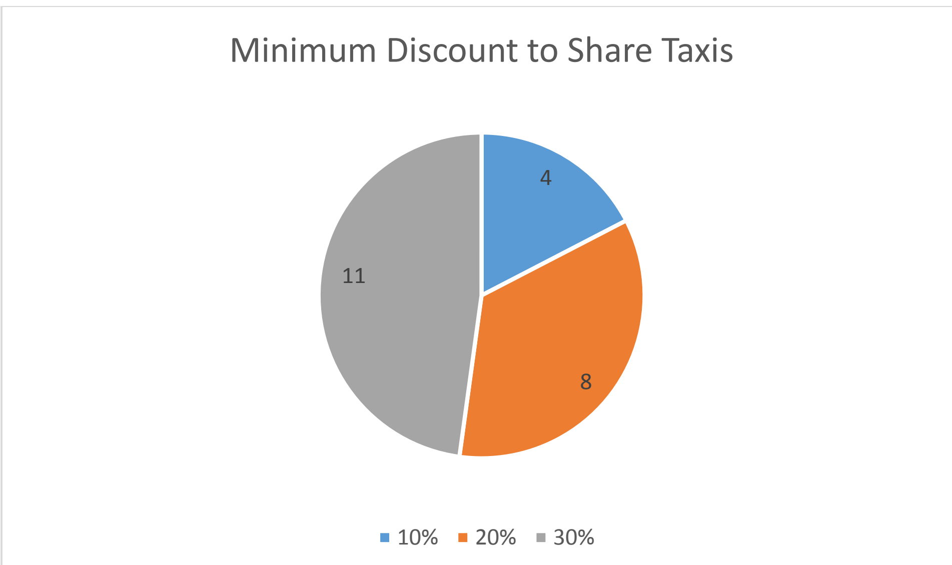
5. (If they did not take a taxi) Did you consider taking a taxi at any point?

Yes	No
6	10

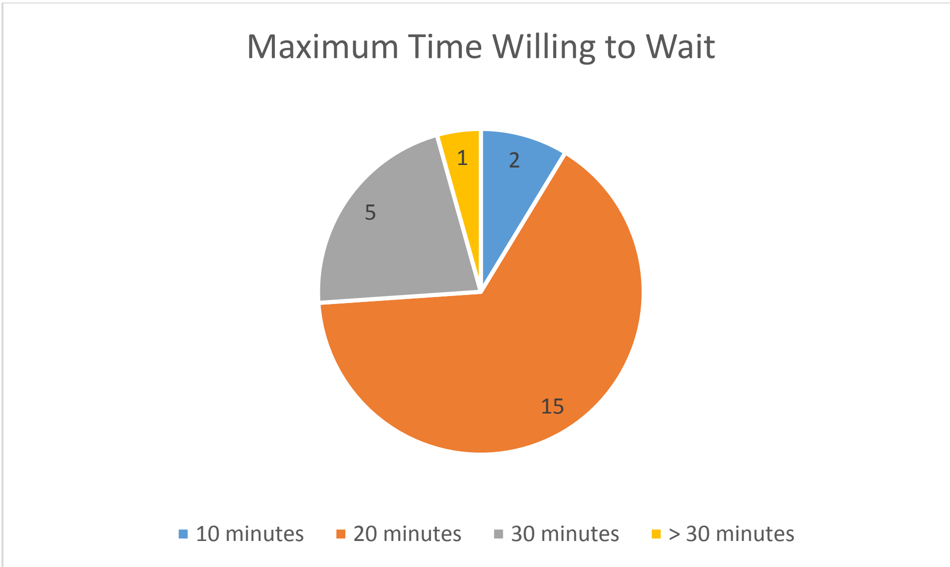
6. Why didn't you take a taxi?

Too Expensive	Lack of Knowledge
14	2

7. Would you share a taxi with other tourists if you received a 10% discount? A 20%? A 30%?



8. If you were to receive a 30% discount, What is the longest you would be willing to wait to join another group interested in sharing a taxi to a location close to your destination (minutes)? >30 30 20 10

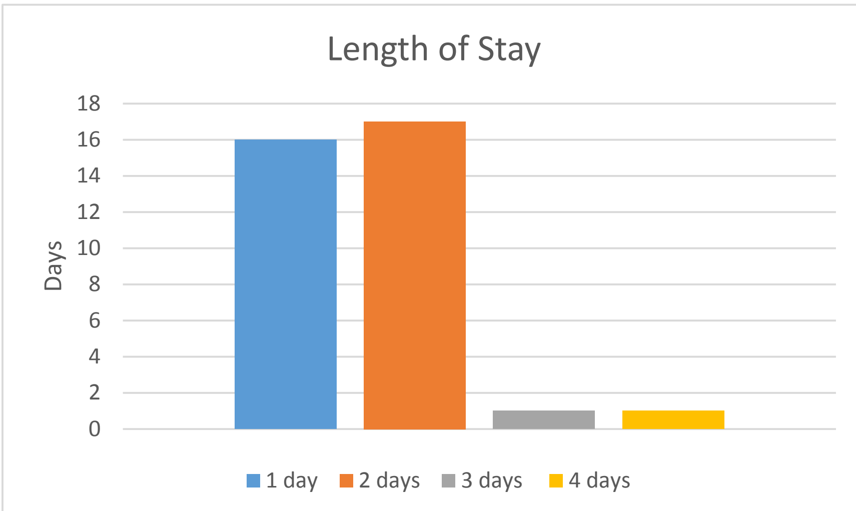

Maximum Time Willing to Wait
1
2
5
15
10 minutes
20 minutes
30 minutes
> 30 minutes

Appendix F. **San Marco Taxi Survey 2 Results**

1. Are you a tourist?

Yes	No
35	0

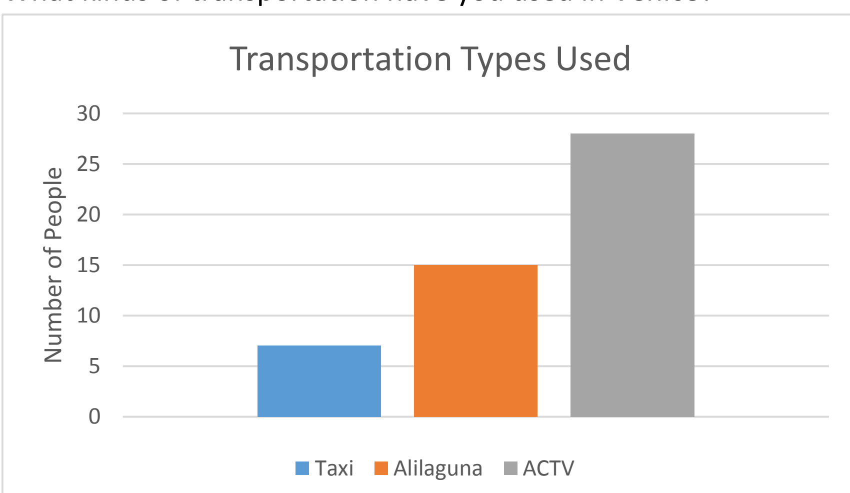
2. How long is/was your stay?



3. Did you bring luggage?

Yes	No
15	20

4. What kinds of transportation have you used in Venice?



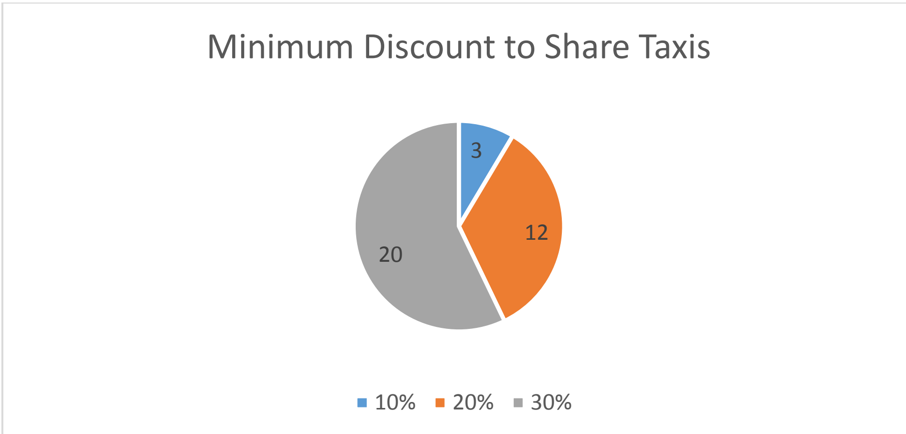
5. (If they did not take a taxi) Did you consider taking a taxi at any point?

Yes	No
6	22

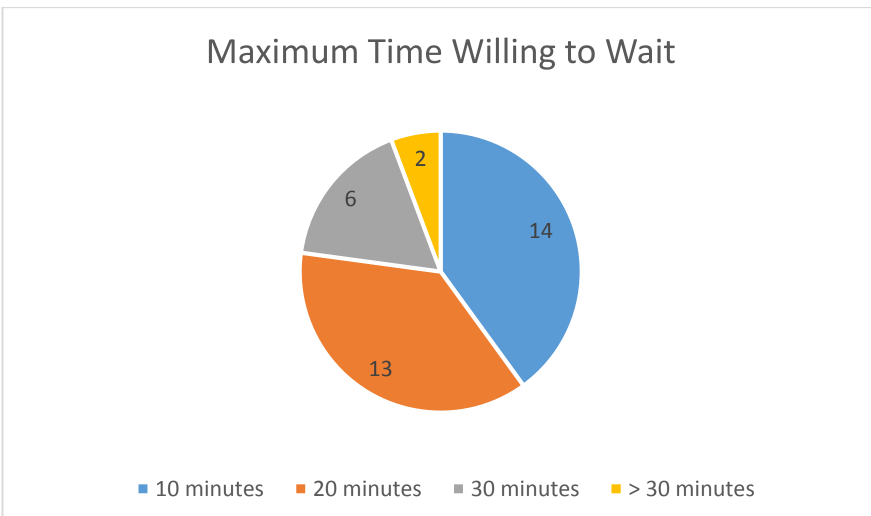
6. (If not) Why not/why didn't you?

Too Expensive	Lack of Knowledge
28	4

7. Would you share a taxi with other tourists if you received a 10% discount? A 20%? A 30%

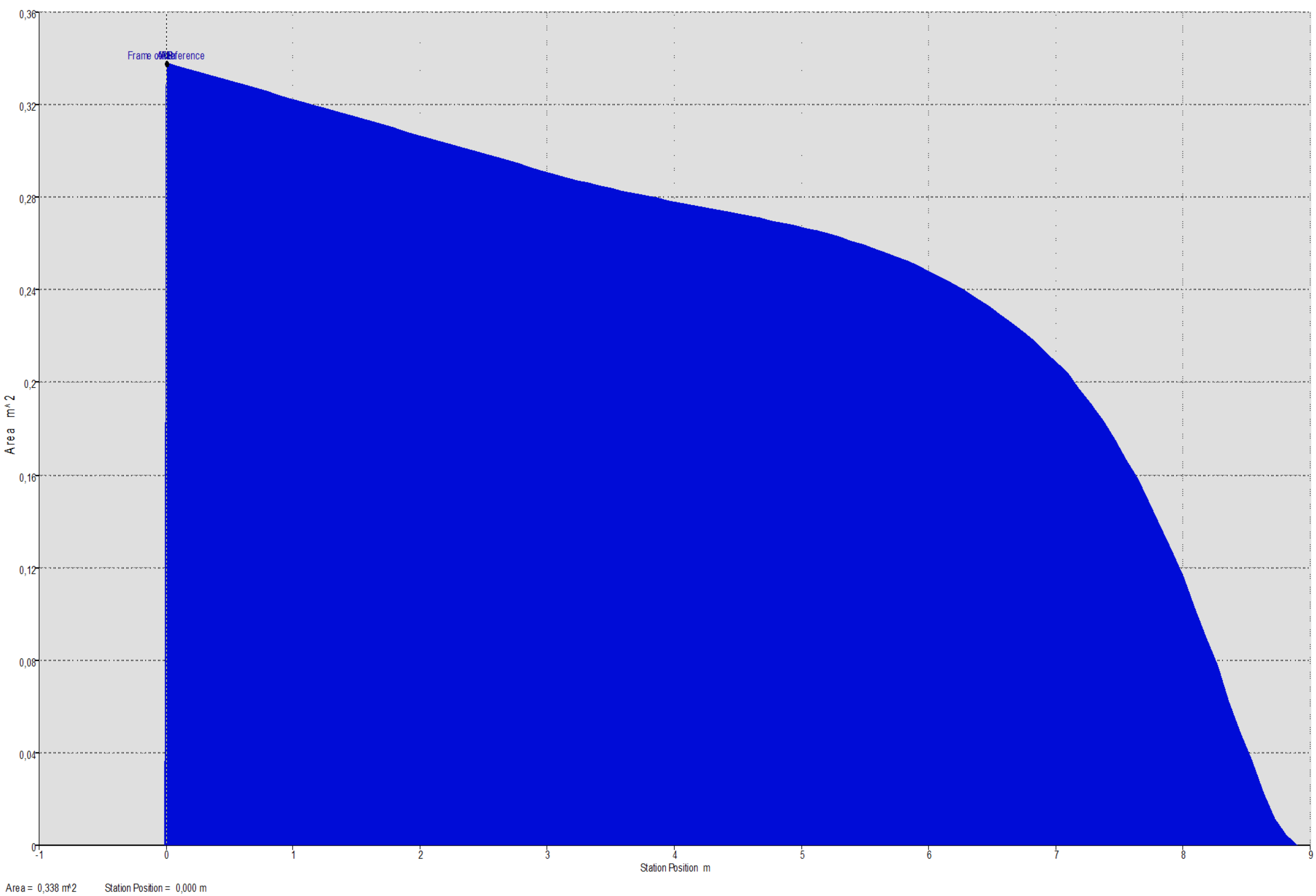


8. If you were to receive a 30% discount, What is the longest you would be willing to wait to join another group interested in sharing a taxi to a location close to your destination (minutes)? >30 30 20 10



Appendix G. **Old Taxi Heavy Hull Data**

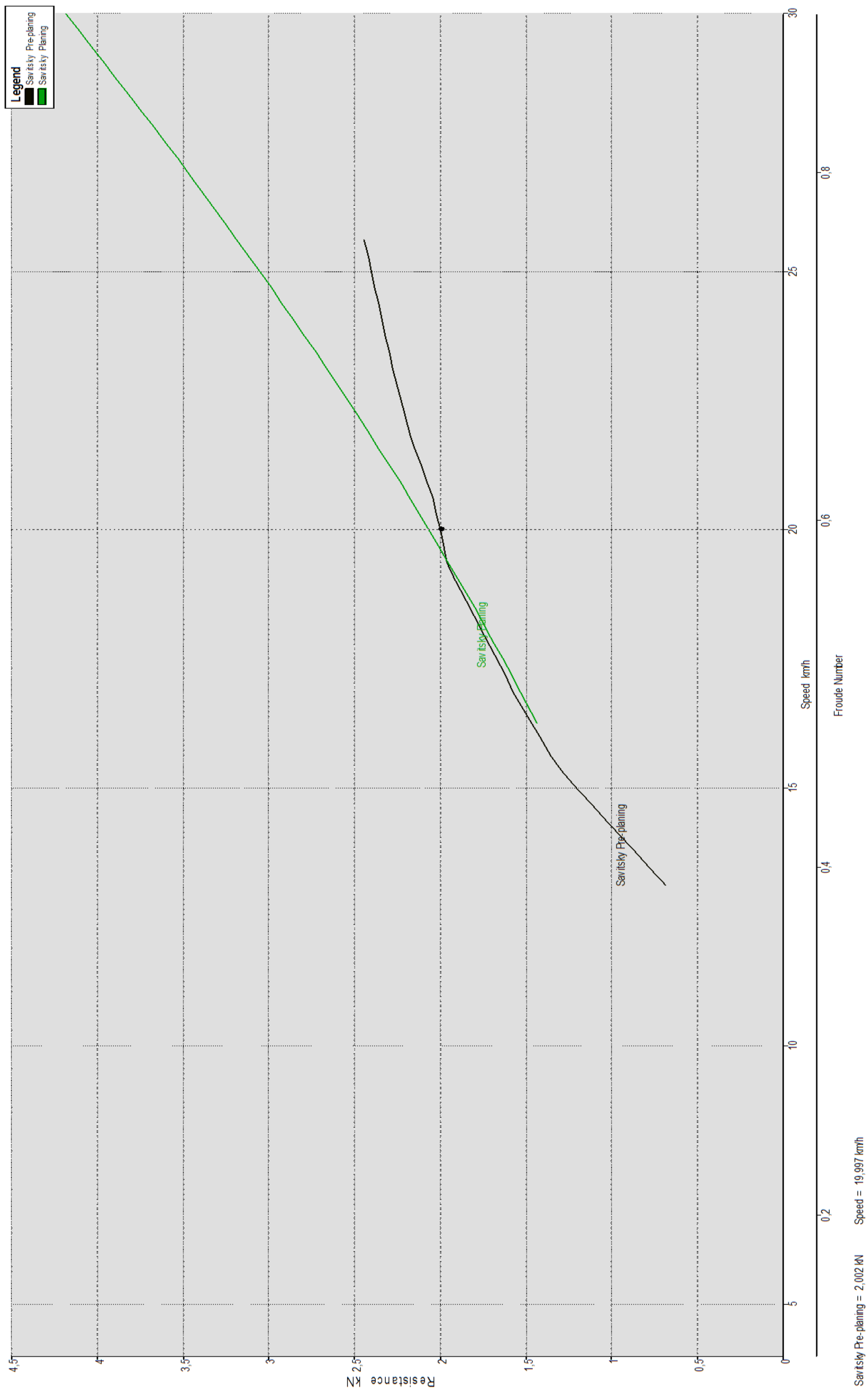
Item	Value	Units
LWL	8.908	m
Beam	2.004	m
Draft	0.336	m
Displaced volume	2.204	m^3
Wetted area	15.252	m^2
Prismatic coeff. (Cp)	0.732	
Waterpl. area coeff. (Cwp)	0.785	
1/2 angle of entrance	20.1	deg.
LCG from midships(+ve for'd)	3.698	m
Transom area	0	m^2
Transom wl beam	0	m
Transom draft	0	m
Max sectional area	0.338	m^2
Bulb transverse area	0.338	m^2
Bulb height from keel	0	m
Draft at FP	0	m
Deadrise at 50% LWL	19.5	deg.
Hard chine or Round bilge	Hard chine	
Frontal Area	0	m^2
Headwind	0	km/h
Drag Coefficient	0	
Air density	0.001	tonne/m^3
Appendage Area	0	m^2
Nominal App. length	0	m
Appendage Factor	1	
Correlation allow.	0.0004	
Kinematic viscosity	1.188E-06	m^2/s
Water Density	1.026	tonne/m^3



Frame of Reference
Area m^2
0,36
0,32
0,28
0,24
0,2
0,16
0,12
0,08
0,04
0
-1
0
1
2
3
4
5
6
7
8
9
Station Position m
Area = 0,338 m^2
Station Position = 0,000 m

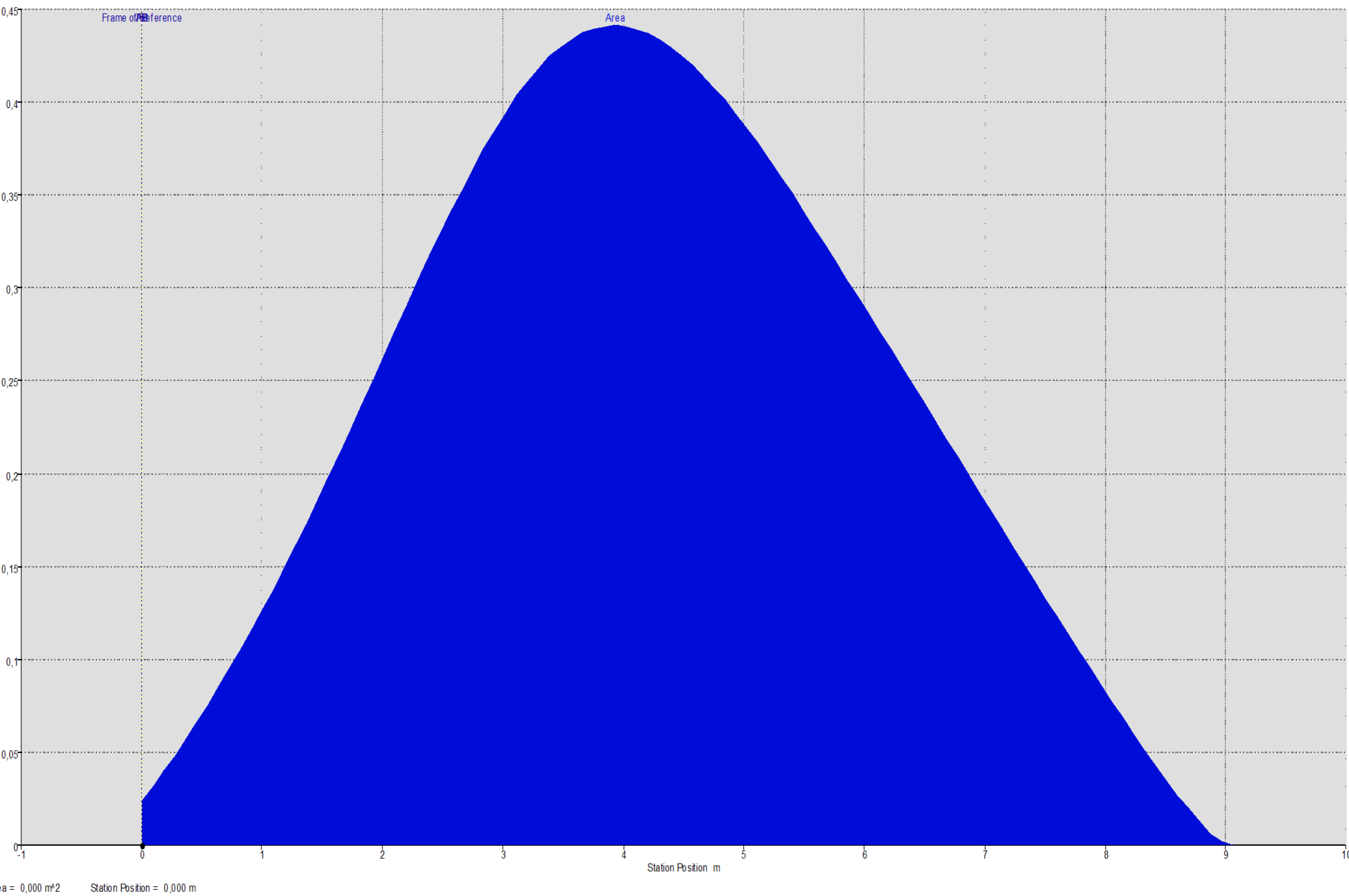
Appendix H. **Old Taxi Heavy Hull Results**

Km/h	Fn Lwl	Fn Vol	Holtrop KN
5	0.147	0.389	0.1
5.625	0.166	0.438	0.1
6.25	0.184	0.487	0.1
6.875	0.203	0.535	0.1
7.5	0.221	0.584	0.2
8.125	0.239	0.632	0.2
8.75	0.258	0.681	0.2
9.375	0.276	0.73	0.3
10	0.295	0.778	0.3
10.625	0.313	0.827	0.3
11.25	0.332	0.876	0.4
11.875	0.35	0.924	0.5
12.5	0.368	0.973	0.6
13.125	0.387	1.022	0.7
13.75	0.405	1.07	0.8
14.375	0.424	1.119	0.9
15	0.442	1.168	1
15.625	0.46	1.216	1.1
16.25	0.479	1.265	1.2
16.875	0.497	1.314	1.3
17.5	0.516	1.362	1.4
18.125	0.534	1.411	1.5
18.75	0.553	1.46	1.6
19.375	0.571	1.508	1.6
20	0.589	1.557	1.7
20.625	0.608	1.606	1.8
21.25	0.626	1.654	1.8
21.875	0.645	1.703	1.9
22.5	0.663	1.751	2
23.125	0.681	1.8	2
23.75	0.7	1.849	2.1
24.375	0.718	1.897	2.2
25	0.737	1.946	2.3
25.625	0.755	1.995	2.3
26.25	0.774	2.043	2.4
26.875	0.792	2.092	2.5
27.5	0.81	2.141	2.6
28.125	0.829	2.189	2.7
28.75	0.847	2.238	2.8
29.375	0.866	2.287	2.9
30	0.884	2.335	3


Legend
Savitsky Pre-planing
Savitsky Planing
Savitsky Planing
Savitsky Pre-planing
Resistance kN
Speed km/h
Froude Number
Savitsky Pre-planing = 2,002 kN
Speed = 19,997 km/h

Appendix I. **New Taxi Heavy Hull Data**

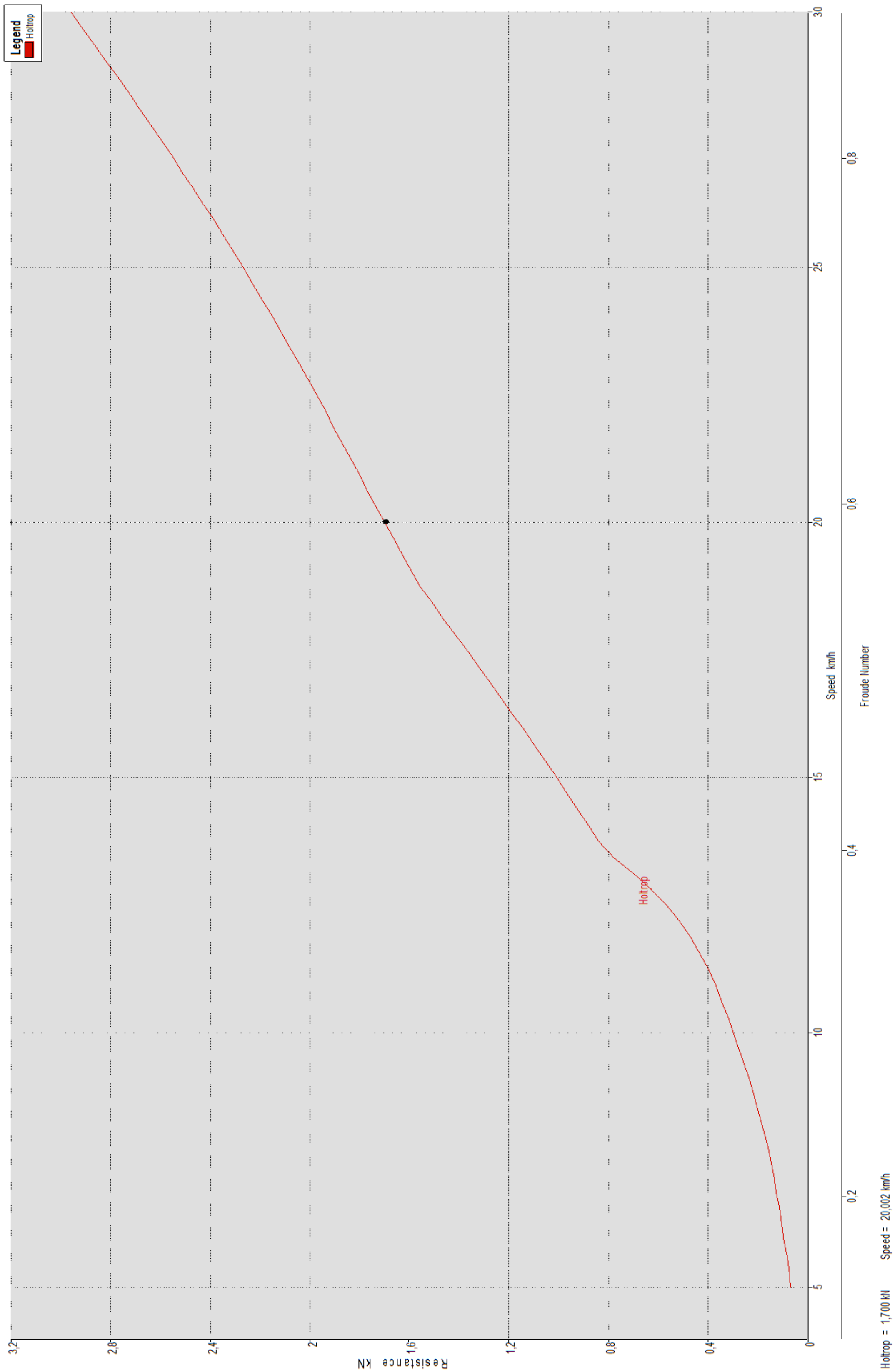
Item	Value	Units	
LWL	9.061	m	
Beam	2.171	m	
Draft	0.45	m	
Displaced volume	2.189	m^3	
Wetted area	15.244	m^2	
Prismatic coeff. (Cp)	0.548		
Waterpl. area coeff. (Cwp)	0.685		
1/2 angle of entrance	12.5	deg.	
LCG from midships(+ve for'd)	4.233	m	
Transom area	0	m^2	
Transom wl beam	0	m	
Transom draft	0.02	m	
Max sectional area	0.441	m^2	
Bulb transverse area	0	m^2	
Bulb height from keel	0	m	
Draft at FP	0	m	
Deadrise at 50% LWL	23.8	deg.	
Hard chine or Round bilge	Round Bilge		
Frontal Area	0	m^2	
Headwind	0	km/h	
Drag Coefficient	0		
Air density	0.001	tonne/m^3	
Appendage Area	0	m^2	
Nominal App. length	0	m	
Appendage Factor	1		
Correlation allow.	0.0004		
Kinematic viscosity	1.19E-06	m^2/s	
Water Density	1.026	tonne/m^3	



Frame of Reference
AB
Area
0,45
0,4
0,35
0,3
0,25
0,2
0,15
0,1
0,05
0
-1
0
1
2
3
4
5
6
7
8
9
10
Station Position m
a = 0,000 m^2
Station Position = 0,000 m

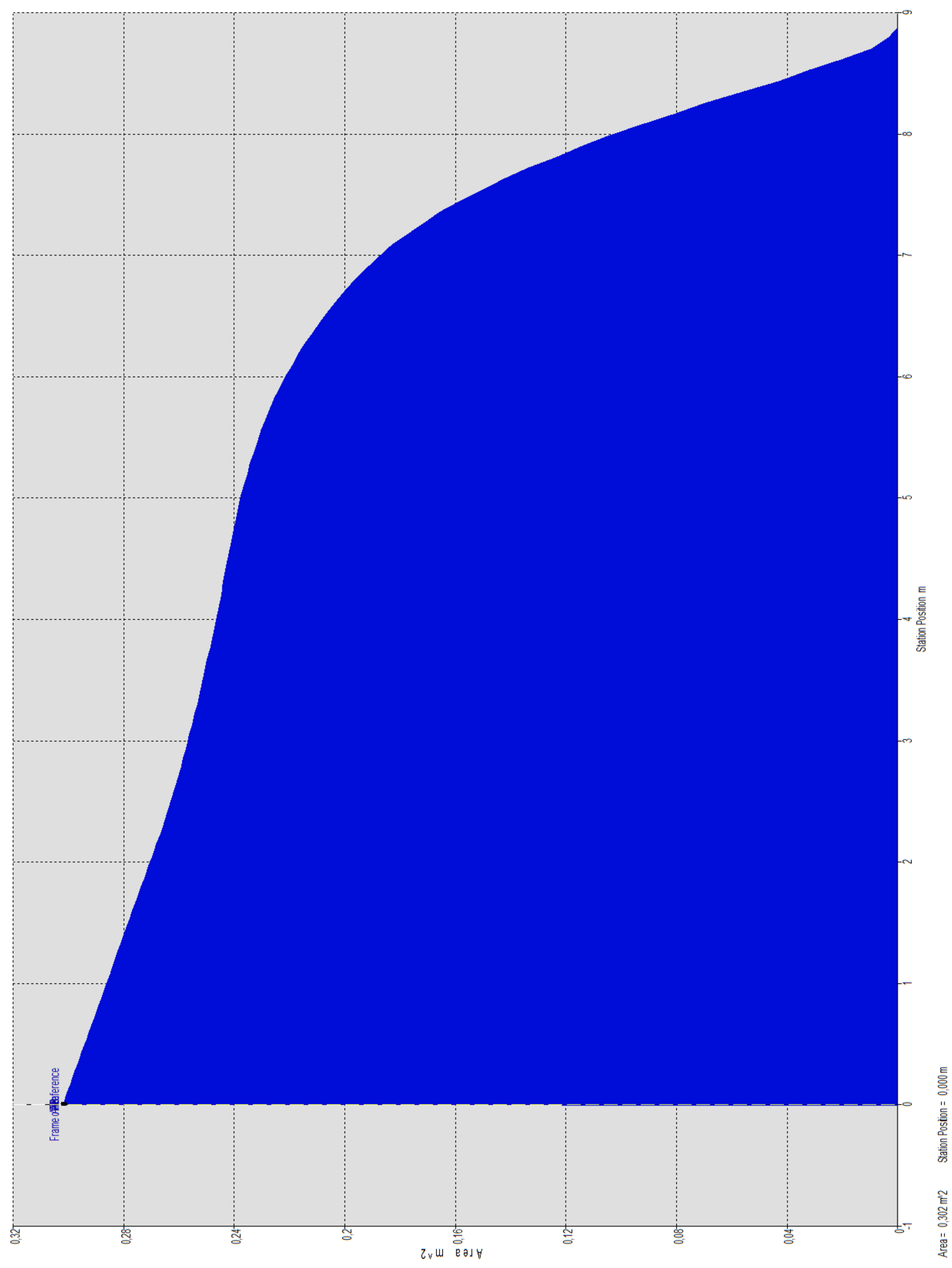
Appendix J. **New Taxi Heavy Hull Results**

Km/h	Fn Lwl	Fn Vol	Holtrop KN
5	0.147	0.389	0.1
5.625	0.166	0.438	0.1
6.25	0.184	0.487	0.1
6.875	0.203	0.535	0.1
7.5	0.221	0.584	0.2
8.125	0.239	0.632	0.2
8.75	0.258	0.681	0.2
9.375	0.276	0.73	0.3
10	0.295	0.778	0.3
10.625	0.313	0.827	0.3
11.25	0.332	0.876	0.4
11.875	0.35	0.924	0.5
12.5	0.368	0.973	0.6
13.125	0.387	1.022	0.7
13.75	0.405	1.07	0.8
14.375	0.424	1.119	0.9
15	0.442	1.168	1
15.625	0.46	1.216	1.1
16.25	0.479	1.265	1.2
16.875	0.497	1.314	1.3
17.5	0.516	1.362	1.4
18.125	0.534	1.411	1.5
18.75	0.553	1.46	1.6
19.375	0.571	1.508	1.6
20	0.589	1.557	1.7
20.625	0.608	1.606	1.8
21.25	0.626	1.654	1.8
21.875	0.645	1.703	1.9
22.5	0.663	1.751	2
23.125	0.681	1.8	2
23.75	0.7	1.849	2.1
24.375	0.718	1.897	2.2
25	0.737	1.946	2.3
25.625	0.755	1.995	2.3
26.25	0.774	2.043	2.4
26.875	0.792	2.092	2.5
27.5	0.81	2.141	2.6
28.125	0.829	2.189	2.7
28.75	0.847	2.238	2.8
29.375	0.866	2.287	2.9
30	0.884	2.335	3


Legend
Holtrop
Holtrop
Resistance kN
Speed km/h
Froude Number
Holtrop = 1,700 kN
Speed = 20,002 km/h
0
0,4
0,8
1,2
1,6
2
2,4
2,8
3,2
5
10
15
20
25
30
0,2
0,4
0,6
0,8

Appendix K. **Old Taxi Light Hull Data**

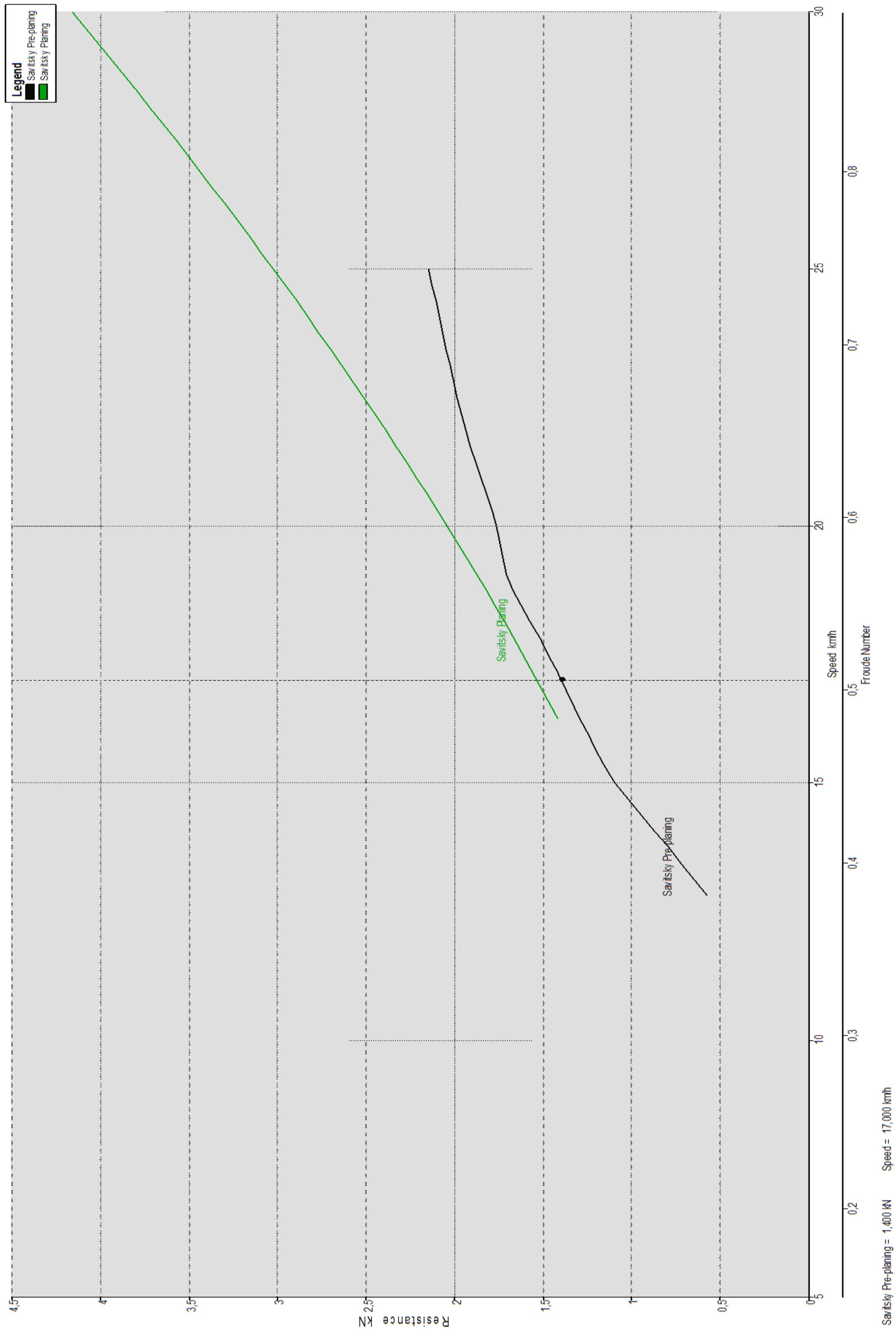
Item	Value	Units
LWL	8.89	m
Beam	2.002	m
Draft	0.318	m
Displaced volume	1.957	m^3
Wetted area	14.534	m^2
Prismatic coeff. (Cp)	0.729	
Waterpl. area coeff. (Cwp)	0.755	
1/2 angle of entrance	19.4	deg.
LCG from midships(+ve for'd)	3.7	m
Transom area	0	m^2
Transom wl beam	2	m
Transom draft	0	m
Max sectional area	0.302	m^2
Bulb transverse area	0.302	m^2
Bulb height from keel	0	m
Draft at FP	0	m
Deadrise at 50% LWL	19.4	deg.
Hard chine or Round bilge	Hard chine	
Frontal Area	0	m^2
Headwind	0	km/h
Drag Coefficient	0	
Air density	0.001	tonne/m^3
Appendage Area	0	m^2
Nominal App. length	0	m
Appendage Factor	1	
Correlation allow.	0.0004	
Kinematic viscosity	1.19E-06	m^2/s
Water Density	1.026	tonne/m^3



Area m^2
0,32
0,28
0,24
0,2
0,16
0,12
0,08
0,04
0
-1
0
1
2
3
4
5
6
7
8
9
Station Position m
Frame of Reference
Area = 0,302 m^2
Station Position = 0,000 m

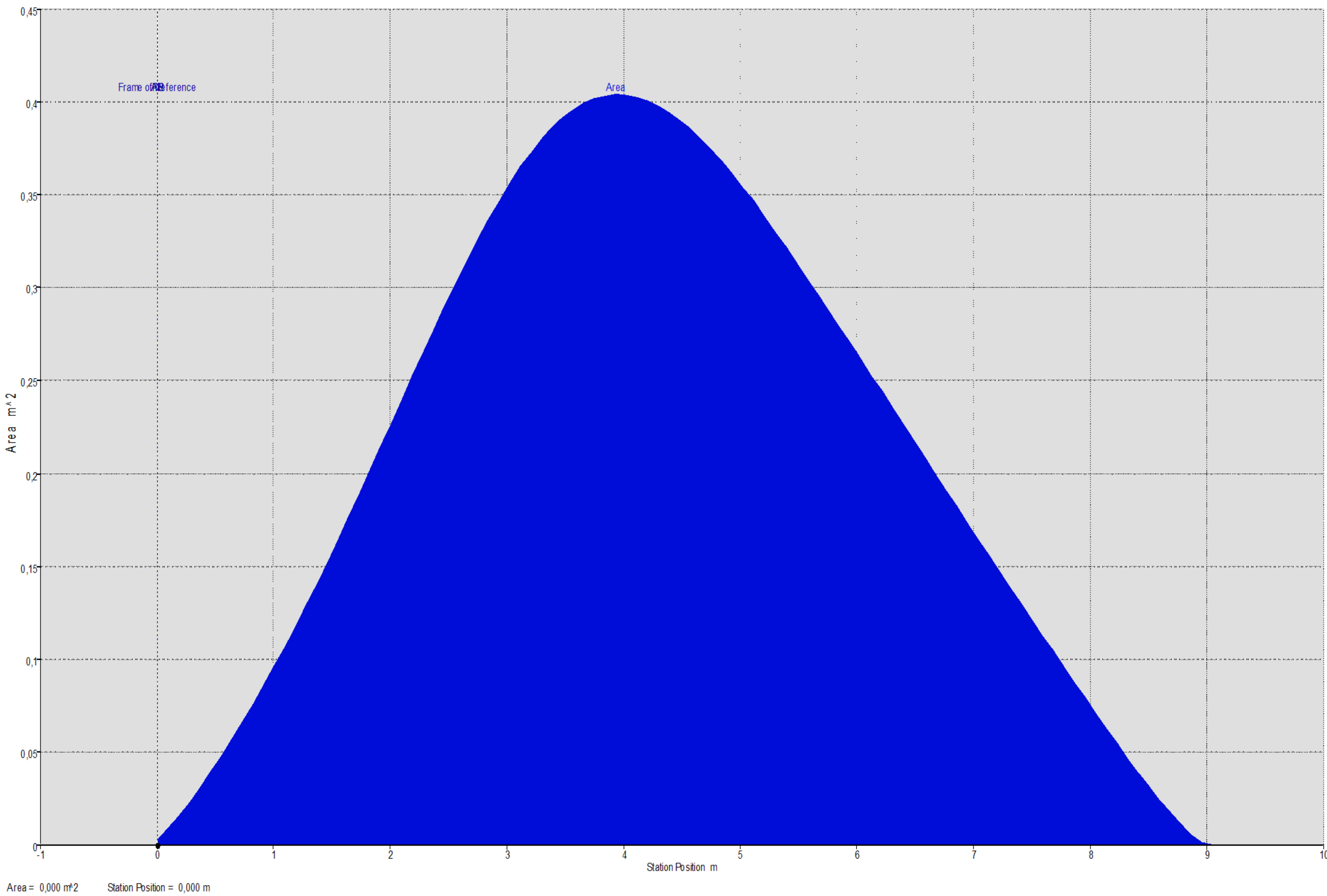
Appendix L. **Old Taxi Light Hull Results**

Km/h	Fn Lwl	Fn Vol	Savitsky Pre Planing KN	Savitsky Planing KN
5	0.149	0.397	--	--
5.625	0.167	0.446	--	--
6.25	0.186	0.496	--	--
6.875	0.205	0.545	--	--
7.5	0.223	0.595	--	--
8.125	0.242	0.644	--	--
8.75	0.26	0.694	--	--
9.375	0.279	0.744	--	--
10	0.297	0.793	--	--
10.625	0.316	0.843	--	--
11.25	0.335	0.892	--	--
11.875	0.353	0.942	--	--
12.5	0.372	0.991	--	--
13.125	0.39	1.041	0.6	--
13.75	0.409	1.091	0.8	--
14.375	0.428	1.14	0.9	--
15	0.446	1.19	1.1	--
15.625	0.465	1.239	1.2	--
16.25	0.483	1.289	1.3	1.4
16.875	0.502	1.338	1.4	1.5
17.5	0.521	1.388	1.5	1.6
18.125	0.539	1.437	1.6	1.7
18.75	0.558	1.487	1.7	1.8
19.375	0.576	1.537	1.7	1.9
20	0.595	1.586	1.8	2
20.625	0.614	1.636	1.8	2.2
21.25	0.632	1.685	1.9	2.3
21.875	0.651	1.735	1.9	2.4
22.5	0.669	1.784	2	2.5
23.125	0.688	1.834	2	2.6
23.75	0.707	1.884	2.1	2.8
24.375	0.725	1.933	2.1	2.9
25	0.744	1.983	2.1	3
25.625	0.762	2.032	--	3.2
26.25	0.781	2.082	--	3.3
26.875	0.8	2.131	--	3.4
27.5	0.818	2.181	--	3.6
28.125	0.837	2.231	--	3.7
28.75	0.855	2.28	--	3.9
29.375	0.874	2.33	--	4
30	0.892	2.379	--	4.2


Legend
Savitsky Pre-planing
Savitsky Planing
Savitsky Planing
Savitsky Pre-planing
Resistance KN
Speed kmh
Froude Number
Savitsky Pre-planing = 1,400 kN
Speed = 17,000 kmh

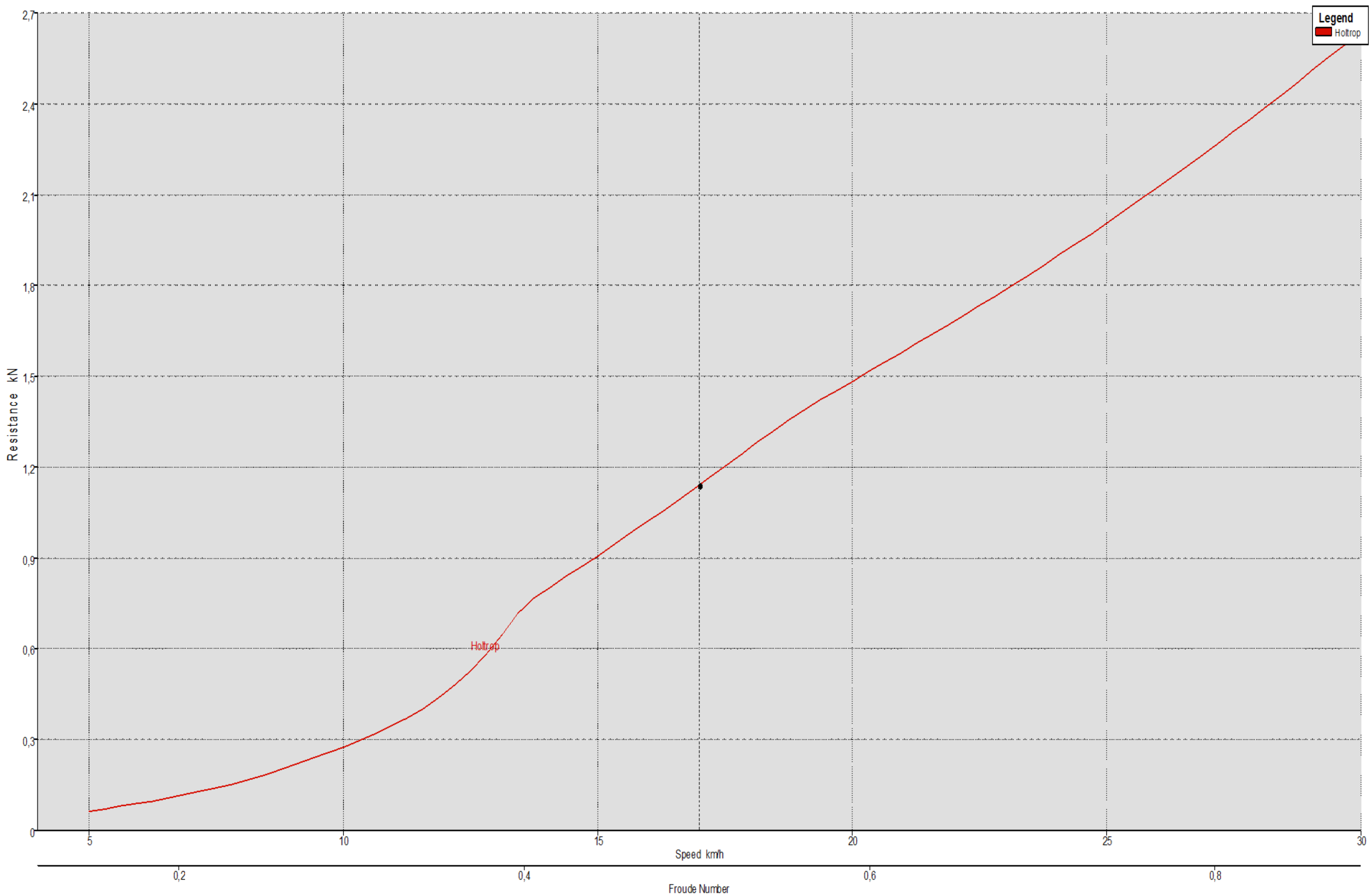
Appendix M. **New Taxi Light Hull Data**

Item	Value	Units
LWL	9.049	m
Beam	2.088	m
Draft	0.432	m
Displaced volume	1.953	m^3
Wetted area	14.375	m^2
Prismatic coeff. (Cp)	0.534	
Waterpl. area coeff. (Cwp)	0.672	
1/2 angle of entrance	12	deg.
LCG from midships(+ve for'd)	4.302	m
Transom area	0	m^2
Transom wl beam	0	m
Transom draft	0.002	m
Max sectional area	0.404	m^2
Bulb transverse area	0	m^2
Bulb height from keel	0	m
Draft at FP	0	m
Deadrise at 50% LWL	23.8	deg.
Hard chine or Round bilge	Hard chine	
Frontal Area	0	m^2
Headwind	0	km/h
Drag Coefficient	0	
Air density	0.001	tonne/m^3
Appendage Area	0	m^2
Nominal App. length	0	m
Appendage Factor	1	
Correlation allow.	0.0004	
Kinematic viscosity	1.19E-06	m^2/s
Water Density	1.026	tonne/m^3


Frame of Reference
Area
0,45
0,4
0,35
0,3
0,25
0,2
0,15
0,1
0,05
0
Area m^2
-1
0
1
2
3
4
5
6
7
8
9
10
Station Position m
Area = 0,000 m^2
Station Position = 0,000 m

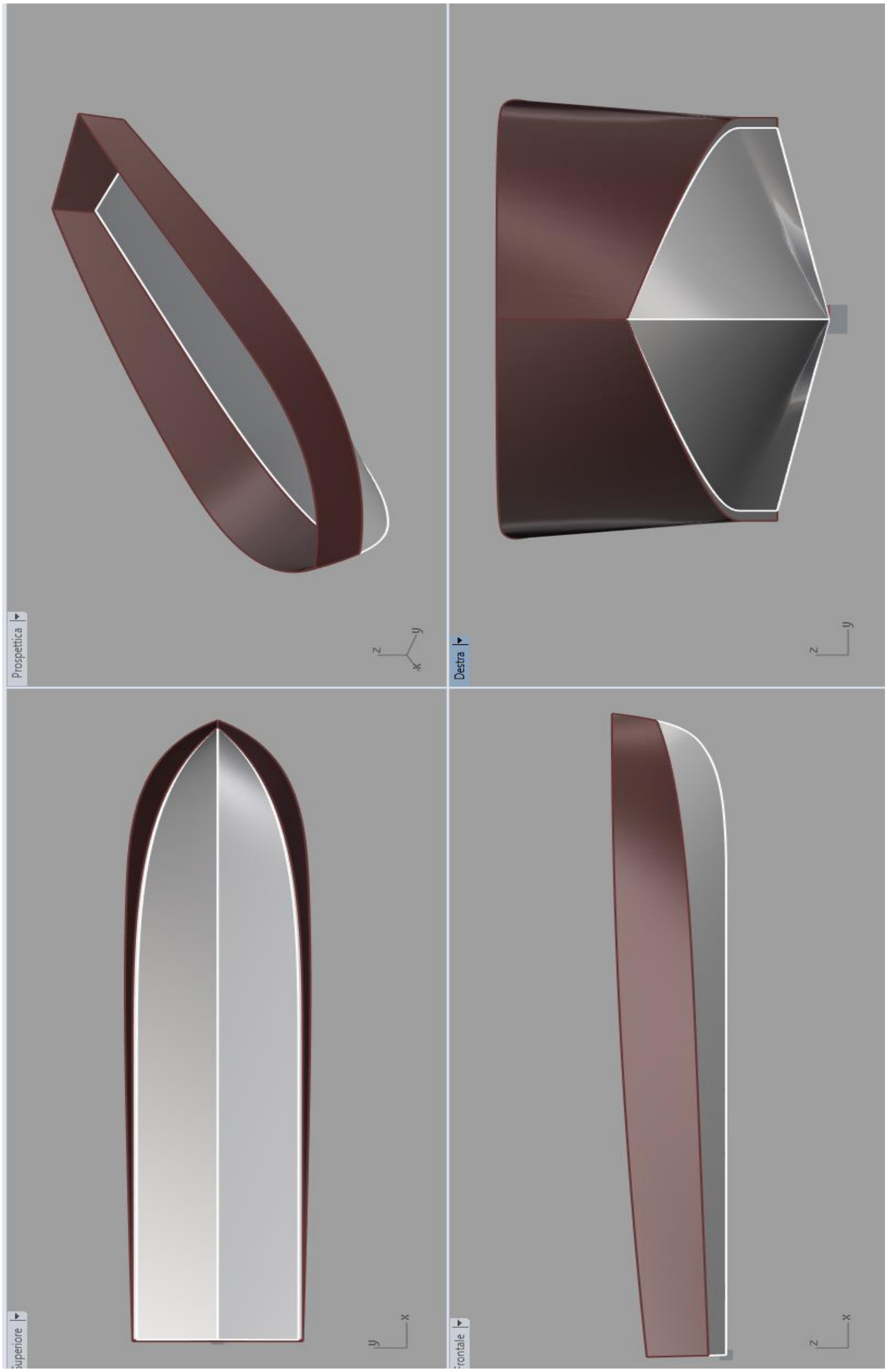
Appendix N. **New Taxi Light Hull Results**

A	B	C	D
Km/h	Fn Lwl	Fn Vol	Holtrop KN
5	0.147	0.397	0.1
5.625	0.166	0.446	0.1
6.25	0.184	0.496	0.1
6.875	0.203	0.545	0.1
7.5	0.221	0.595	0.1
8.125	0.24	0.645	0.2
8.75	0.258	0.694	0.2
9.375	0.276	0.744	0.2
10	0.295	0.793	0.3
10.625	0.313	0.843	0.3
11.25	0.332	0.893	0.4
11.875	0.35	0.942	0.4
12.5	0.369	0.992	0.5
13.125	0.387	1.041	0.6
13.75	0.405	1.091	0.8
14.375	0.424	1.14	0.8
15	0.442	1.19	0.9
15.625	0.461	1.24	1
16.25	0.479	1.289	1.1
16.875	0.498	1.339	1.1
17.5	0.516	1.388	1.2
18.125	0.534	1.438	1.3
18.75	0.553	1.488	1.4
19.375	0.571	1.537	1.4
20	0.59	1.587	1.5
20.625	0.608	1.636	1.5
21.25	0.627	1.686	1.6
21.875	0.645	1.735	1.7
22.5	0.663	1.785	1.7
23.125	0.682	1.835	1.8
23.75	0.7	1.884	1.9
24.375	0.719	1.934	1.9
25	0.737	1.983	2
25.625	0.756	2.033	2.1
26.25	0.774	2.083	2.2
26.875	0.792	2.132	2.2
27.5	0.811	2.182	2.3
28.125	0.829	2.231	2.4
28.75	0.848	2.281	2.5
29.375	0.866	2.331	2.6
30	0.885	2.38	2.6

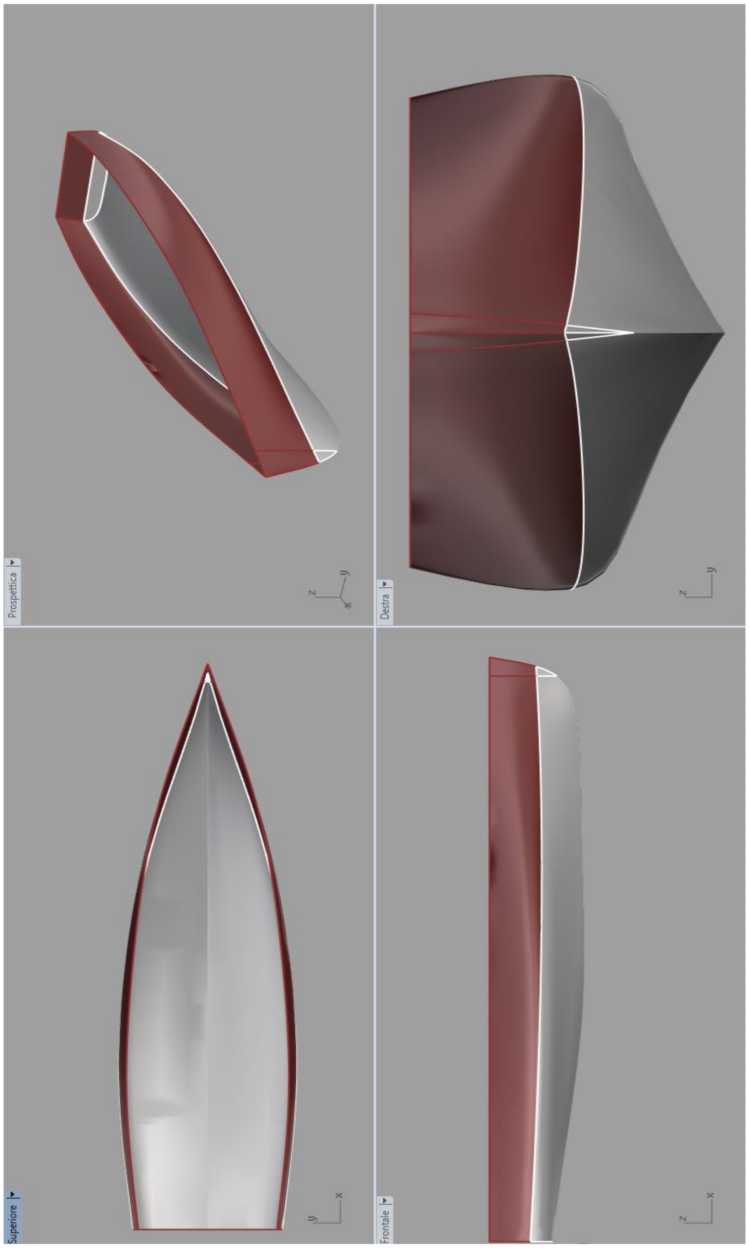


Holtrop = 1,142 kN Speed = 17,000 km/h

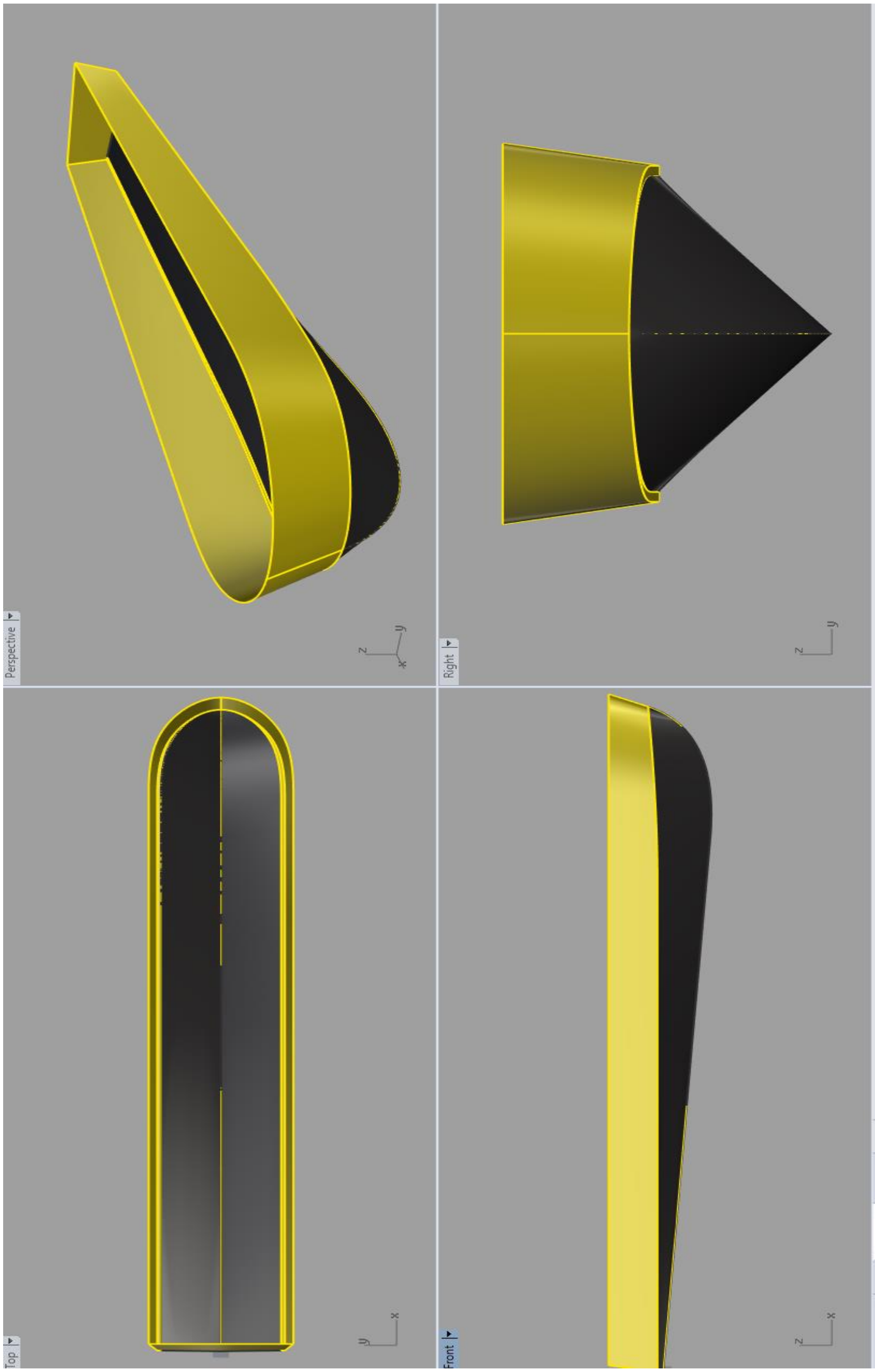
Appendix O. **Four-Sided View of Current Taxi**



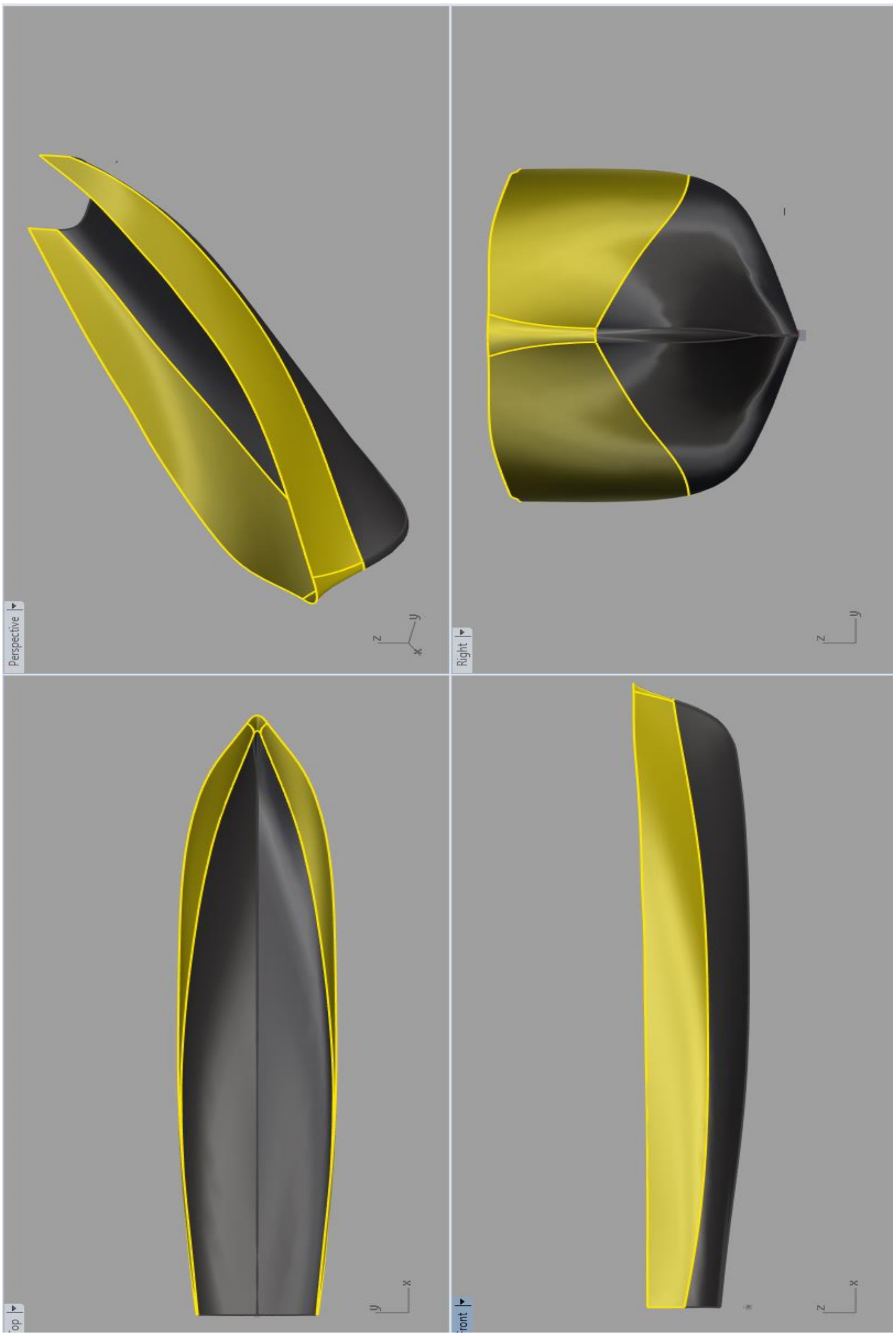
Appendix P. **Four-Sided View of New Taxi**



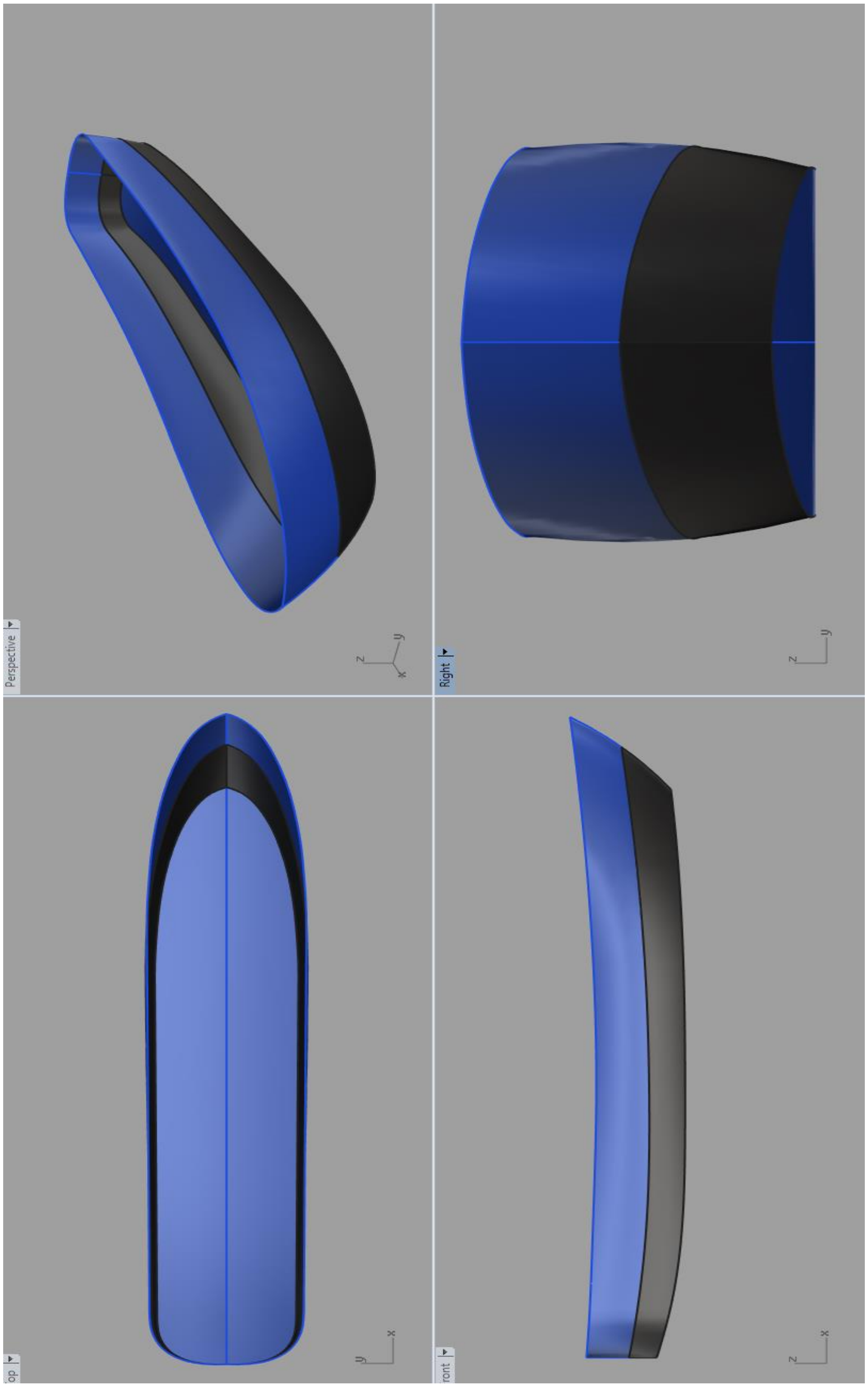
Appendix Q. **Four-Sided View of Current *Alilaguna***



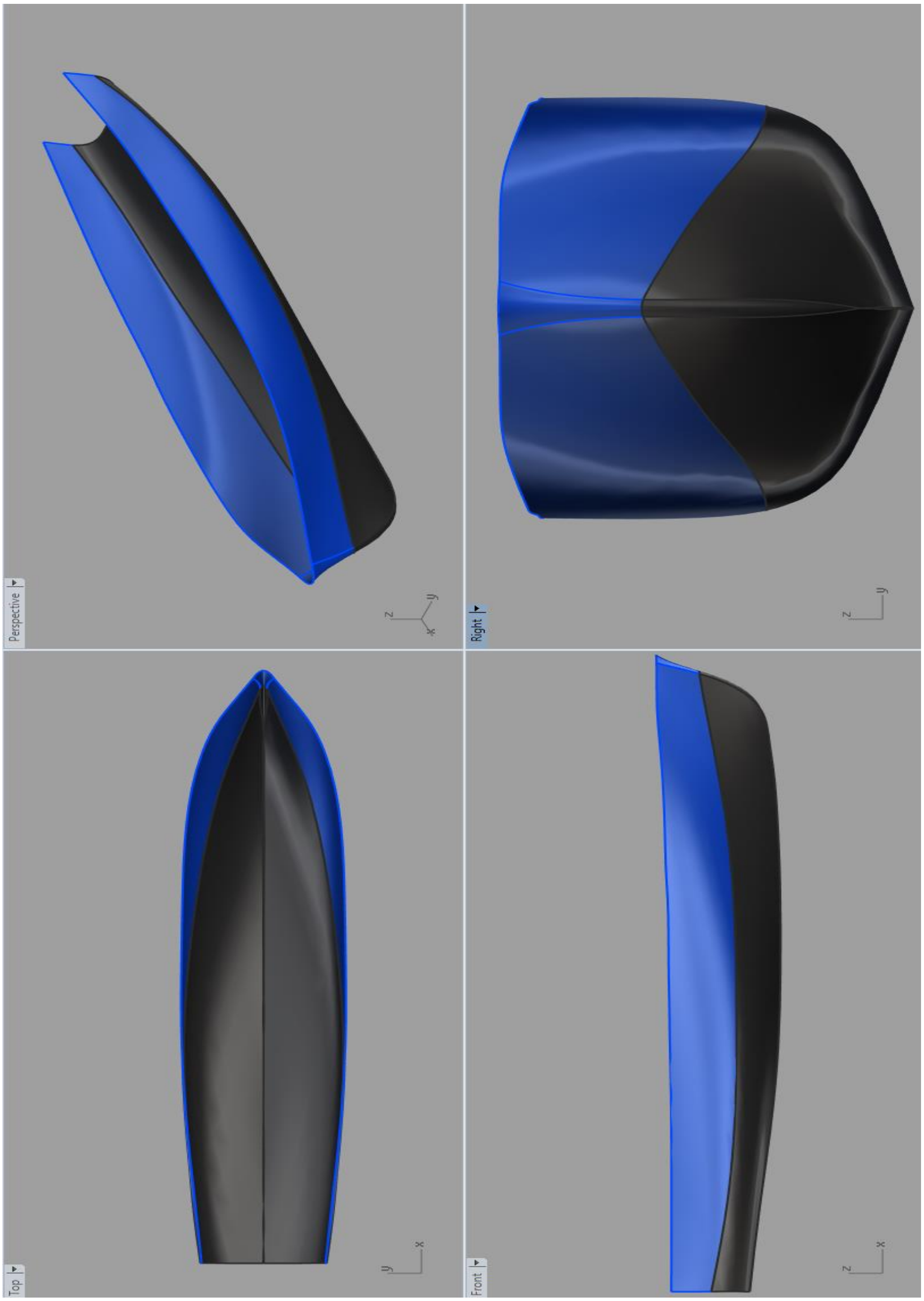
Appendix R. **Four-Sided View of New *Alilaguna***



Appendix S. **Four-Sided View of Current Cargo**



Appendix T. **Four-Sided View of New Cargo**



Appendix U. **The Five Year Plan**

Year 1 (13% reduction)

The first year focuses on what can be done immediately to reduce *moto ondoso*, and how to set-up for the future. The first thing to do would be to more strictly enforce regulations on speed limits in the canals. A 2013 study estimated there could be 26% less *moto ondoso* if all boats followed the speed limit, as opposed to the 19% which currently do.[59] Then, the recommended cruise ship passenger data collection and procedures of contacting *Alilaguna* workers and cruise ship companies should be conducted. After any necessary changes are made, the *Alilaguna* schedule should be updated and synchronized with cruise ship arrivals. This will include the bursts of *Alilaguna Linea Blu* boats for each cruise ship arrival. This change should see an immediate increase in the efficiency of passenger transport from cruise ships by boat as well as a decrease in *moto ondoso* due to a decrease in the number of boat trips needed.

A taxi-sharing system needs to be introduced to the city and infrastructure built to support it. This would involve hiring out a software developer to build an app that could help travelers and taxi drivers connect, and perhaps building out separate lines at taxi stands for those willing to participate in taxi-sharing. A survey of the taxi drivers should be undertaken to see how they would organize such a system. Additionally, laws could be changed to allow taxis to take certain shortcuts they currently are not allowed through, or to allow them to pick up passengers without having to return to their stand.

The *Interscambio Merci* needs to be rented out and put to use. The money has already been spent to build it but it has sat unused for over a decade, and is a crucial part of switching to a by-location delivery system. The bid process is already underway, so whichever consortium the city chooses should be able to move in at some point during 2016. The rent contract may include clauses committing the consortium to using a by-location delivery system using the methods outlined in this report, but this first year will primarily be used to setup and prepare for deployment of the system during the second year. An important of this setup will be to assess which zones Venice should be split into, and more importantly, allow for this zoning system to be dynamic. Cargo volume can vary from day to day, and the zones need to be adjustable in order to allow for these changes.

Finally, new boat hulls should continue to be studied and refined in the 3D modelling software. Hydrodynamic analysis needs to be completed on all the hulls to confirm the changes

[59] (Bennett et al. 2013)

provide a uniform 29% reduction across all boats. Once the boat hulls are completed in software, they'll be ready for year two when the hulls will actually be built and tested.

Overall, a conservative estimate for the first year of reductions is 13%. This is based around the reduction achievable from enforcing speed limits, which is 26%. Since it is unreasonable to assume that perfect enforcement will occur, a conservative estimate of 13% reduction is given.

Year 2 (35% reduction)

During the second year, the taxi-sharing app will be introduced and advertising will begin throughout the city of Venice and on travel websites where both tourists and local Venetians will see it. This will initiate the use of the app, which should begin to see immediate results as more people share taxis now that they are able to take them at lower prices than before. A 2006 taxi study estimated that taxi-sharing would reduce overall *moto ondoso* by 14%. Next, the complete cargo tracking system will be implemented. The opt-in efficiency tracking program with by-location delivery should begin to see immediate results as cargo boat drivers will be incentivized to use this program, therefore reducing overall *moto ondoso*. We estimate that if all cargo transporters participated in a by-location system, a 30% reduction in global *moto ondoso* would be possible. Since the cargo consortium likely to control the warehouse represents about 70% of all the cargo boats in Venice, we expect this number to be a 21% reduction. Finally, full sized models of the new boat hulls will be created and tested in a towing tank in order to begin research on this. At the end of this year, there should be an overall *moto ondoso* reduction of about 35%.

Year 3 (0% - 29% reduction)

The third year of this plan will see the introduction of the new cargo and taxi hulls in Venice. This will begin by gauging the interest of taxi and cargo boat drivers in the new hulls. A financial incentive program would be designed for those who switch, since they are saving the structural integrity and safety of the city. Easy-to-find information on the differences between old and new hulls will be provided as well to both the drivers and boat manufacturers. This switch to the new boat hulls will not be able to be immediately adopted, and will take time to see results, but the overall reduction moto ondoso should be increased to about 50%.

Year 4 (0% - 29% reduction, continued)

The fourth year of this plan involves the introduction of the new Alilaguna boat hulls. Moto ondoso can be reduced up to 29% along with the other boat hull introductions from the previous year. Incentives will be created for using the more efficient boat hulls that could either be a discount on total cost or a tax break.

Year 5 (77% combined reduction)

The final year of this plan will be dedicated to reassessing the systems created in the previous years. The taxi sharing app should be assessed for popularity and usage. The by-location delivery system for cargo transportation will be assessed for efficiency and effectiveness. ACTV should also consider implementing the M-hull, which would be long-term projects to reduce almost of the *moto ondoso* they are responsible for. If all the recommendations made are taken into account and all hulls are switched, *moto ondoso* can be reduced up to 77% in the City of Venice.

Appendix V. Number of Packages Going to Each Zone

Zone	Total Dry Packages	Total Ref. Packages
1	153	30
2	382	81
3	178	55
4	1479	297
5	964	144
6	337	73
7	369	50
8	113	20
9	363	59
10	567	125
11	1032	203
12	371	97
13	410	53
14	802	135
15	455	72
16	733	142
17	560	122
18	2677	520
19	357	78
20	1015	259
21	538	82
22	881	126
23	380	54
24	303	71
25	910	186
26	370	45
27	799	126
28	244	53
29	348	93
30	1038	158
31	538	111
32	2452	274
33	430	65
34	738	116
35	736	100
36	1028	256

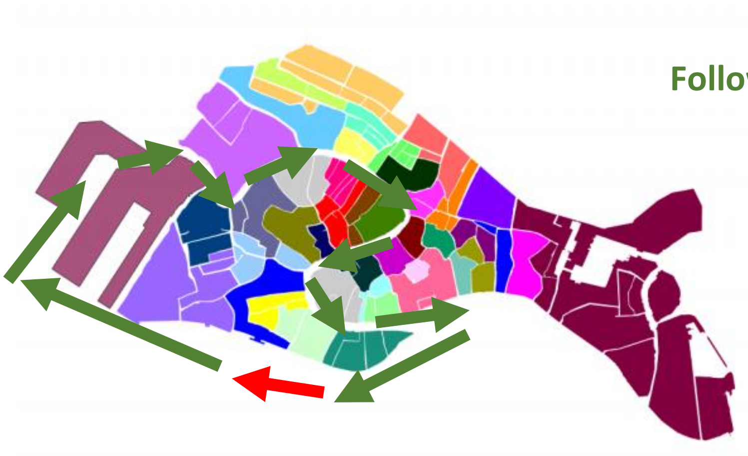
37	570	97
38	250	45
39	267	35
40	286	59
41	709	120
42	196	35

Appendix W. Number of Cargo Boats Necessary per Delivery Zone

Zone	Rounded Dry	Rounded Ref.	**Total Boats**
8	1.00	1.00	2.00
1	1.00	1.00	2.00
3	1.00	1.00	2.00
42	1.00	1.00	2.00
28	1.00	1.00	2.00
38	1.00	1.00	2.00
39	1.00	1.00	2.00
40	1.00	2.00	3.00
24	1.00	2.00	3.00
6	1.00	2.00	3.00
29	1.00	2.00	3.00
7	2.00	1.00	3.00
26	2.00	1.00	3.00
23	2.00	1.00	3.00
13	2.00	1.00	3.00
19	2.00	2.00	4.00
9	2.00	2.00	4.00
12	2.00	2.00	4.00
2	2.00	2.00	4.00
33	2.00	2.00	4.00
15	2.00	2.00	4.00
21	2.00	2.00	4.00
31	2.00	2.00	4.00
37	2.00	2.00	4.00
17	2.00	3.00	5.00
10	2.00	3.00	5.00
35	3.00	2.00	5.00
41	3.00	3.00	6.00
16	3.00	3.00	6.00
34	3.00	3.00	6.00
27	3.00	3.00	6.00
14	3.00	3.00	6.00
22	3.00	3.00	6.00
5	3.00	3.00	6.00
30	3.00	3.00	6.00
25	3.00	4.00	7.00
11	3.00	4.00	7.00

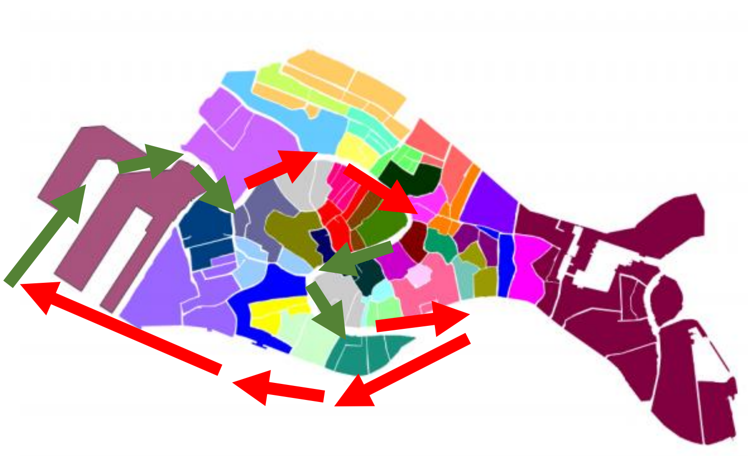
20	3.00	5.00	8.00
36	3.00	5.00	8.00
4	5.00	6.00	11.00
32	8.00	5.00	13.00
18	8.00	10.00	18.00
Totals:	**101.00**	**108.00**	**209.00**

Appendix X. Graphical Representations of Efficiency Restrictions



Followed speed limit most of the time

☑ €467,000

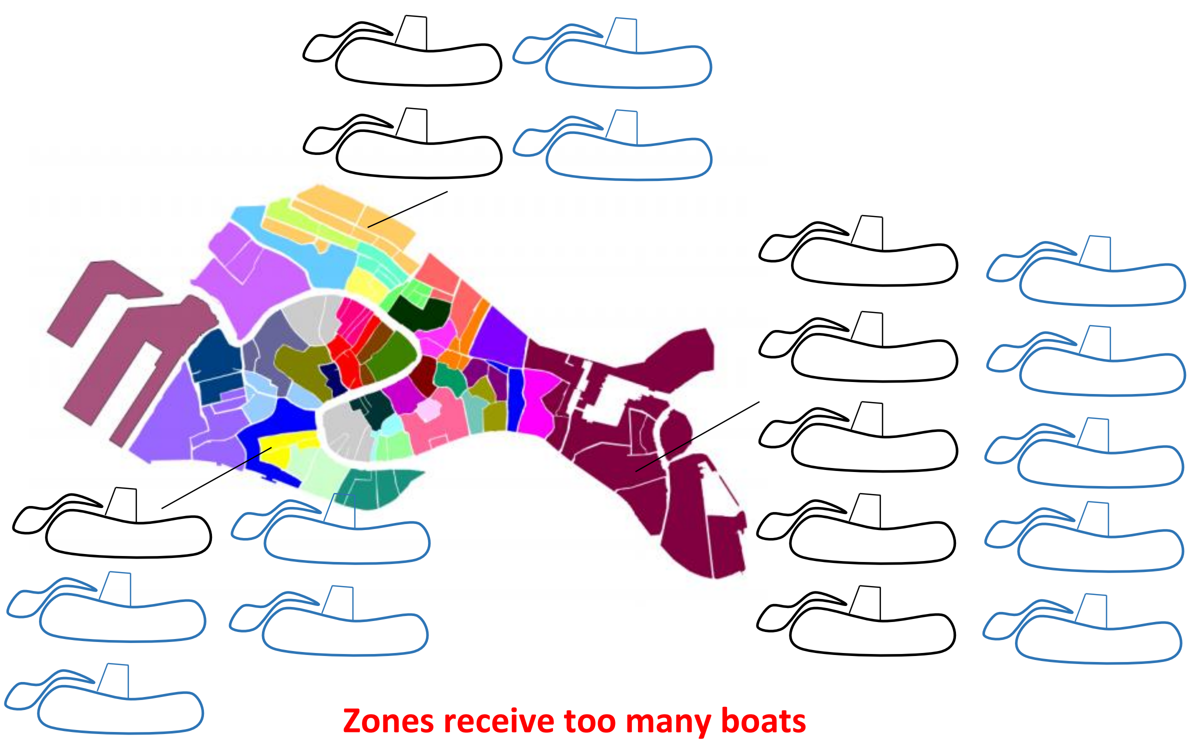


Did not follow speed limit

☒ €500,000

Zones receive correct number of boats

☑ €467,000



Zones receive too many boats

☒ €500,000