The Evolution of Transportation Systems in the Historic City of Venice: Past, Present, and Future

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SMARTDEST
CITIES AS MOBILITY HUBS: TACKLING SOCIAL EXCLUSION THROUGH 'SMART' CITIZEN ENGAGEMENT

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Introduction

The historic city of Venice, Italy has been facing depopulation for several decades. The population has decreased by 125,000 since its peak in 1951 (Comune di Venezia, 2022). Results from the 56 interviews with Venetian emigres conducted by researchers at SerenDPT revealed that the most common reason to leave Venice is for school. On the other hand, most of those emigres stay away from Venice because of job opportunities (rather, a lack thereof). The majority of them would be happy to return to Venice, and "jobs" was the most popular response to being asked what would need to change in order for them to return. However, there are also a lot of Venetians who have stayed in Venice, and the ones who work on the mainland tend to have high-paying jobs. It was also observed that those who work on the mainland are not traveling to very distant locations from the bridge between the mainland and the historic city of Venice – mostly to locations within 30 minutes of travel on the mainland (Carrera, 2020). One way to repopulate Venice is to expand the job market for Venetians by decreasing commute times to the mainland.

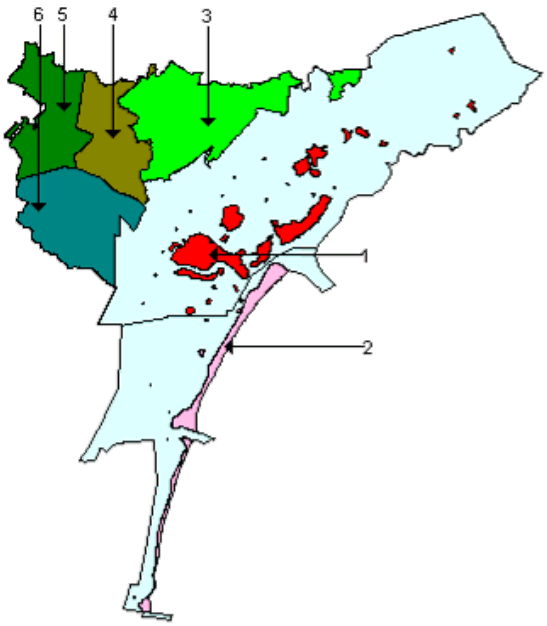
The unique city of Venice is located in the Venetian Lagoon. It's composed of about 120 islands, which are divided by over 160 canals (Treccani, n.d.). Because of this unique geographic structure and lack of wide roads, there are two main modes of transportation in the historic center of Venice: boat and walking (Walsh et al., 2021). However, a large part of the Metropolitan City of Venice lies on the mainland (Comune di Venezia, 2017). In order to commute to the mainland, residents can use a public train, bus, or tram, or drive their car from a parking facility. The hub of transportation in and out of Venice is at the end of the bridge that connects the historic city to the mainland, in western Santa Croce and Cannaregio. The city and its residents have adapted over time to technological advances in transportation and to evolving needs of the city as it has grown.

This project aimed to understand the current Venetian transportation system, especially its limitations and its history, and the potential costs and benefits of an underground subway system. In order to achieve that goal, we first summarized the history of transportation in Venice and how the city has adapted over time to changes in transportation technology and infrastructure. Then, we assessed the current state of transportation in Venice, especially with respect to business travel. Finally, we made the information we had collected about the Venetian transportation system more widely accessible.

Desktop research was crucial to the project. Specifically, we used peer-reviewed journal articles to gather information on the history and current state of the transportation system. An important type of visualization for analyzing travel times in transportation systems is the isochrone–a type of visualization that overlays lines, squares, or other abstract shapes on a map around a "starting point"; the shapes represent the amount of distance that can be covered in a certain amount of time. The Geoapify website, which uses the Isolines API, was used to create isochrones. Most of the sources on Venetian transportation are published by government agencies and transportation agencies in Italian, so we also electronically scanned and translated many of these into English so that future researchers might access them. We made the information accessible by creating a website that holds all of our research, past WPI student research projects relevant to mobility, and visualizations that we created. In what follows, we provide background information on the geography of Venice, detail the history of transportation in the historic city, outline the city's transportation system today and its problems, and describe how a *sublagunare* could decrease commute times for Venetians.

The unique geography of Venice

Veneto is the region of northern Italy where the historic city of Venice, among other cities and many smaller towns, is located (Treccani, n.d.).



- Region 2 (pink): Lido (north) and Pellestrina (south). Lido has cars and buses
- Region 3 (light green): Favaro Veneto
- Region 4 (olive green): Municipality of Mestre, including Carpenedo - Bissuola (east), central Mestre (west)
- Region 5 (dark green): Municipality of Chirignago - Zelarino, also referred to as West Mestre: Cipressina - Zelarino - Trivignano (north), Chirignago - Gazzera (south)
- Region 6 (blue): Municipality of Marghera
- There is a large parking area on the mainland at San Giuliano
- Piazzale Roma (bus terminal, parking), Stazione Marittima (maritime station), Tronchetto (parking), and Ferrovia/Stazione di Santa Lucia (train station) are all located in the area near the end of the Ponte della Libertà in Santa Croce

Figure 1: *Comune di Venezia*, or the Metropolitan City of Venice. The pale blue color represents the Venetian Lagoon. Region 1, which is colored red, represents the Municipality of Venice (the historic center, Murano, and Burano) (Comune di Venezia, 2017).

Within the *Comune di Venezia*, there are other important locations for consideration and understanding of the transportation system. The historic city is typically the focus when discussing the city, but there are many surrounding islands and municipalities.

The *Sestieri* of Venice

Modern-day Venice is split into six *sestieri,* or districts: Cannaregio, Dorsoduro (which includes the islands of Giudecca), San Polo, San Marco, Santa Croce, and Castello (Figure 2). Santa Croce hosts Piazzale Roma (where the bus terminal is located) and the Tronchetto parking facility. The *Stazione di Santa Lucia* (Santa Lucia Train Station), also called *Ferrovia*, is located in Cannaregio (see Figure 11). Although buses and trains can be used to enter the historic city, once on the islands, only boats and walking can be used to get around.

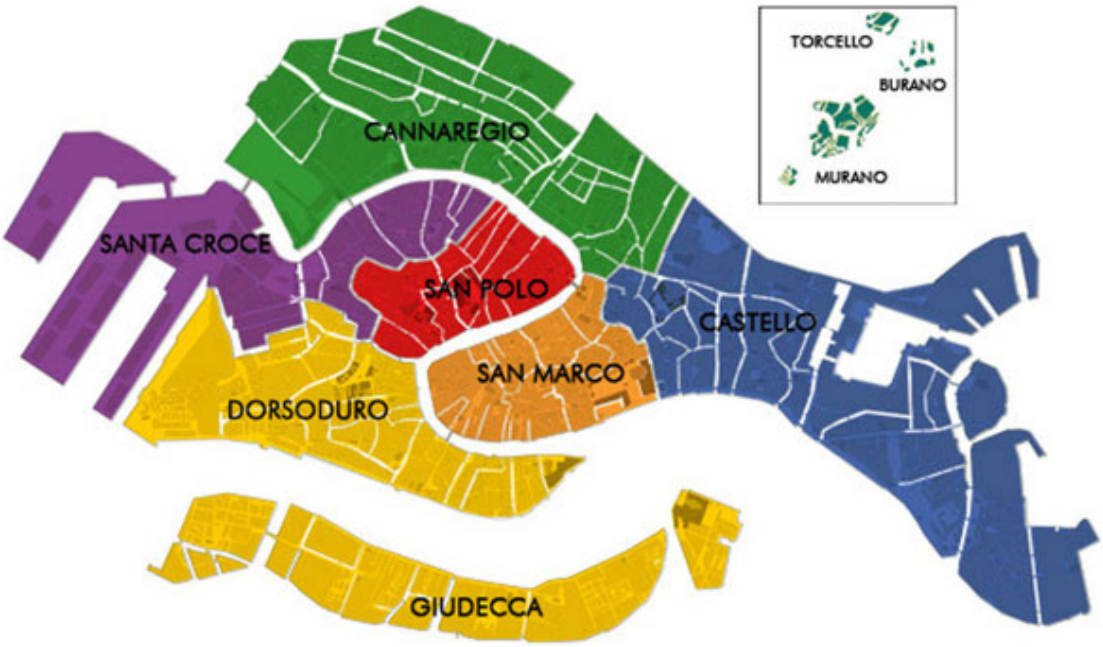


Figure 2: The *sestieri* of Venice. (Evenice, 2017)

Key Developments in Venice's Transportation System, 500 - 1970

Transportation within and around the historic city of Venice has been evolving since the first Venetians set foot on the islands in 421 AD. Walking, made possible by many bridges, and boats, through its many canals, have always been the two main ways of moving within the city, and, before 1846, boats were the only way into and out of the islands from the mainland. During the last two centuries though, two significant leaps occurred with the technology used to transport residents and commuters. The first was connecting the historic city to the mainland by the train bridge, connecting Mestre to Conneregio by train, and the *Ponte della Libertà,* a road bridge running parallel and next to the train bridge, and the second was the development of mechanically propelled boats. Today, Venice needs to take its next big leap in transportation to survive the challenges that tourism brings to its residents and businesses. These major leaps happened after the fall of the Republic of Venice.

As seen in Figure 3, most of the major changes to transportation in Venice occurred very recently and quickly. Each colored line on the top of the timeline corresponds to a different mode of transportation used by the historic city of Venice. In chronological order, blue is row boats of all types, red is horses, light gray is the train system connecting Venice to the mainland, gray is steamboats and black is diesel boats. Of the 1600 years since Venice was founded, only in the last 200 has it gained the technology and infrastructure of a modern city, able to host as many people as it does on its canals and cobblestone *strada* (street).

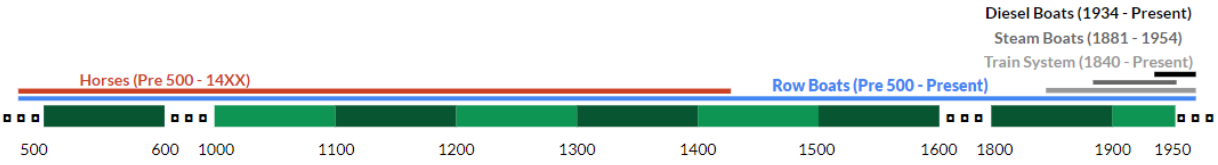


Figure 3: Use of Different Modes of Transportation over time in Venice.

The Groundwork for Future Changes, 500 - 1800

Significant changes in the early stages of Venetian history are few and far between. Despite this, there are some important stepping stones that led to the need for major evolution in the later years of the city. As seen in Figure 4, no new transportation technologies were added between the time Venice was founded and the end of the early era of Venice in 1600. In fact, one of the two main transportation modes slowly became less useful in the environment Venice was creating.

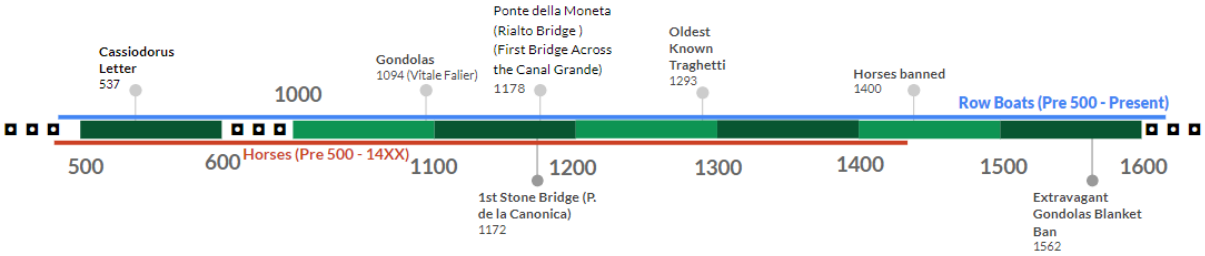


Figure 4: Timeline of Mobility in Venice between 500 and 1600

Venice was founded after the fall of the Roman Empire, with the barbarians sweeping down from northern Europe and by the Veneti who found refuge on the marshland and islands within the lagoon (Avventure Bellissime, 2020). During this time, row boats were the only way to get to the islands from the mainland. Magnus Aurelius Cassiodorus Senator, more commonly known as Cassiodorus, was a monk, writer, and statesman during the reign of Theodoric, king of the Ostrogoths (Encyclopædia Britannica, n.d.). Although not a well-known writer, nor a good one, he did write in a letter in 537 AD that stated, “Therefore diligently repair the ships which you keep tied to the walls of your houses like animals, so that when Laurentius, a man of great experience, who is in charge of procuring these goods, gives you the order, you hasten to go, without delaying the expenses necessary due to some difficulty, you who, depending on the weather conditions, can choose the most suitable route.” (Sartori, U. (Ed.), n.d.). This quote shows how early Venetians lived with the conditions of the islands. Horses were also used to traverse the historic city in the early history of Venice as well. They were useful in crossing smaller canals because they could wade through the waters while carrying products and people.

Early boats in the period were wide and flat bottomed but as the city’s narrow waterways became more crowded, by the 1100th century, a new model was needed that could allow for better flow of transportation within the cities unique canals. These new “Gondolums,” as the Doge refers to them in his letter, replaced the old and most popular boat of the time, the scapula, a much shorter, wider, and symmetrical boat that dates back to the time of the Roman Empire, but the “bloodline” could have come

from any of the boats in the Venetian lagoon (All About Venice, n.d.). A gondola, like the one in Figure 5, is a long and slender flat-bottomed boat that is 10.85 meters long and 1.44 meters wide which allows navigation even in very shallow waters of the lagoon (Vivovenetia, 2022). The first mention of gondolas is from a letter written by Vitale Falier, the Doge (leader) of Venice at the time, to the Venetian people as a “gift” to prevent riots by reducing the water traffic within the city by being thinner and shorter than its predecessors allowing for the boats to pass more easily through the canals (Headout, n.d.). The introduction of Gondolas led to faster travel into and around the city, showing early Venetian evolution.

Figure 5: Ancient Gondola with its intricate designs (Venice Wiki, n.d.)

By the 1100s the use of horses became less frequent. Venice’s uneven terrain and pathways through marshes were paved and more buildings were erected. When Venice added retaining walls to the sides of the islands, horses were no longer easily able to climb into and out of the water, making them less popular. As Venice began to add cobblestone walkways, horses became even less popular because they would slip on the slick stones, as well as paved roads made it easier to walk and pull carts. Around this time, in 1172, the first stone bridge, the Ponte de la Canonica (Figure 6), was constructed. It was built after the assassination of Vital Michiele II in order to have a straight and protected road for the Doge to visit the Church of San Zaccaria (Ab, 2018). Throughout the next few centuries, horses became less and less useful and popular until the 15th century, when they were outright banned by the Venetian noble class, preferring Gondolas as the main travel method within the historic city. This banning of horses allowed for the horse infrastructure in the city to no longer be required, such as fields for grazing.

Figure 6: Ponte de la Canonica in front of the Bridge of Sighs (Durand C., 2019)

Bridges crossing the *Canal Grande* also allowed walking to become an easier way of travel within the city. Only four bridges span the Canal Grande in Venice today. The first bridge constructed in Venice that spans the Canal Grande was the *Ponte della Moneta*, as you can see in Figure 7. Nicolò Barattieri originally designed it in 1178 as a wooden pontoon bridge (Britannica et al., 2021). It was rebuilt in 1255 and 1264 because of collapses and, after multiple collapses of the old bridge, it was replaced by the *Rialto* Bridge in the late 16th century, making it the oldest bridge to cross the Canal Grande (Britannica et al., 2021). The redesign and rebuilding of the *Rialto* Bridge were completed by Antonio de Ponte and his nephew, Antonio Contino (Britannica et al., 2021).

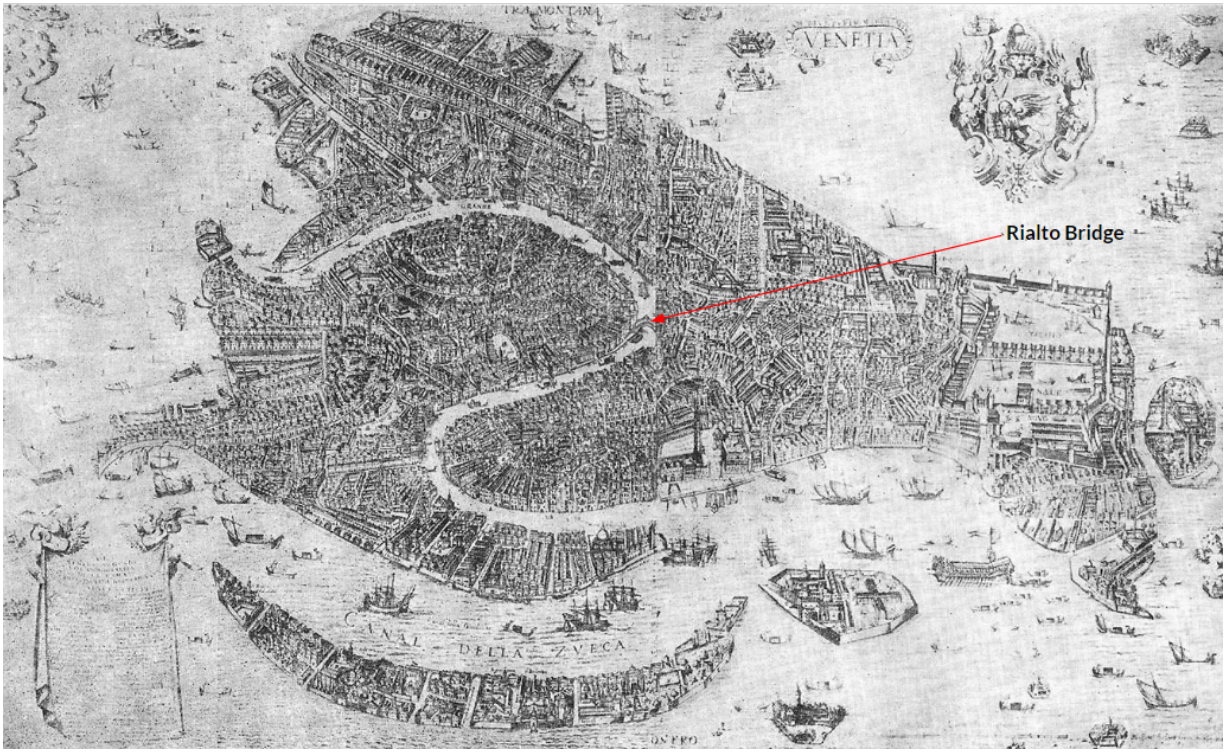


Figure 7: Ancient Map of Venice with the Rialto (De Tollenaere, n.d.)

Between the 14th and 16th Century, *traghetti* were the most common way to travel throughout the city. *Traghetti* were also used to transport people and goods from the mainland to the historic city, as well as the surrounding islands, like Murano (Zanelli et al., 2004). Gondolas were the most common boat used as *traghetti*, and each gondola had its own gondolier. Historic documents show that gondoliers commonly had complaints about them, anywhere from swearing at the passengers to robbing them (Morelli, n.d.). This mistreatment of passengers led to the wealthy citizens and nobles purchasing their own private gondolas and hiring their own gondoliers. Eventually, gondolas became a way of showing wealth by having very colorful and decorative rides throughout the city. In the 16th century, a blanket ban of all extravagant gondolas was put in place to make all the gondolas in the canal black, the same color of the paint used to keep the wood from becoming rotten (Morelli, n.d.).

In 1797, the Republic of Venice fell and the city of Venice began to be put under control of Austrian occupation (ItaliaOutdoors, n.d.). This meant the ending of Venetian isolation, and the beginning of modernization in the city, which had major effects on transportation systems used by the city.

Motorization and Modernization of Venice, 1800 - 1970

Venice has done a good job in the past of maintaining its modernity in comparison to the world around it. Within 40 years of the first steam train in the world beginning to run, Venice had a train bridge built connecting to the mainland. Within 70 years of the first steam boat, Venice had 8 of its own running routes in the *Canal Grande*. Within 60 years of the first car patent, Venice had a car bridge and within 20 years of the first diesel boat, Venice had its own.

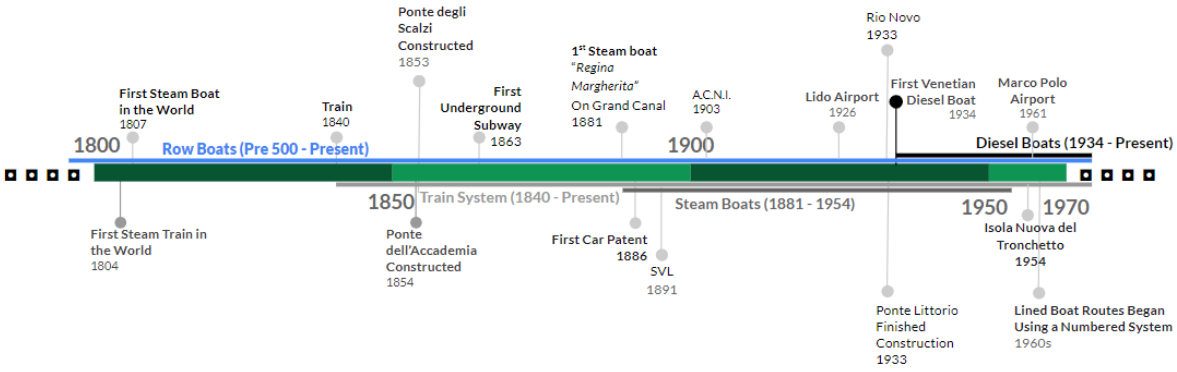


Figure 8: Timeline of Mobility in Venice between 1800 and World War 2

Another historical bridge that spans the canal is the *Ponte dell'Accademia* (Accademia Bridge). Connecting San Marco and Dorsoduro, it is located just before the Canal Grande feeds into the St. Mark's Basin (Imboden, D, n.d.). Originally constructed in 1854 out of steel by A.E. Neville, it remained in its steel form until 1932 when it was replaced with what was supposed to be a temporary, yet identical wooden bridge, which has remained there ever since (Imboden, D, n.d.). The other two bridges crossing the Canal Grande were built in the more modern era.

Prior to 1846, the only way to reach the historic city of Venice was by boat, but under Giuseppe Garibaldi, during that year, Italy was working on a train network project connecting Italy through Milan (Smith et al. 2022). In 1846, Venice was connected to this train line, becoming the last stop on the Milan-Venice line. In order to connect Venice, a train bridge was constructed from Mestre to Cannaregio, as seen in Figure 9 (Mazzetto, S, n.d.). Attached to the end of the Milan-Venice railway is the *Santa Lucia* Train Station, which began construction in 1860, 18 years after the Mestre Station opened (Archetectuul, n.d.).

While the *Santa Lucia* Train Station was being built, under Mussolini, a new road and footbridge built alongside the already standing train bridge into Venice was constructed and was originally named the *Ponte del Littorio*, connecting western Santa Croce to Mestre. The main architect, Eugenio Miozzi, wrote:

"On July 27, 1931, the works for the road connection with the mainland began and were completed on April 25, 1933, after only twenty-one months. It was a grandiose work: the bridge crossing the lagoon is in fact four kilometers long and twenty meters wide; another four kilometers of road were built on the swampy lands of the salt marshes to reach the town of Mestre: the said bridge remained the longest bridge in the world [currently the longest in Italy] and required three hundred kilometers of stilts, forty thousand cubic meters of concrete, twenty thousand cubic meters of bricks, forty-five thousand tons of freestone," (Vigolo, S, n.d.).

In 1945, it was renamed Ponte della Libertà, translating to Liberty Bridge, when Italy became a democracy instead of a dictatorship (Vigolo, S, n.d.). This was the second jump in Venetian transportation. The bridge allowed a large number of people to enter and exit the historic city to and from the mainland much more quickly than before.

Figure 9: Historic City and the Mainland. (On the World Map, n.d.)

While transportation by train was already in full swing and used by most of the Western World, plans for steam-powered boats were still in their early stages of development. When steam-powered boats became a form of public transportation, they were not widely used by Europe, with Venice being the exception, becoming the city's primary form of public transportation (Playfair, 2021). In 1881, Venice's Commune approved the usage of 12 steam-powered *vaporetti*, or little steamers, in the *Canal Grande* (Playfair, 2021). The first 2 *vaporetti* were constructed in France, while the rest were built in Italy (Playfair, 2021). In that year, the first mechanically propelled water vessel, named "*Regina Margherita*", began its first use ever only in the Grand Canal, allowing the general public to have a faster method of water travel (Kimchae, 2012).

In 1883, Torcello, Malamocco, and Pellestrina were added to routes, then in 1887 Murano and Fusina were also added (Playfair, 2021). In 1890, the *Societa Veneta Lagunare* (Venetian Lagoon Society) took over the public transportation services from the French company operating at the time; in 1891, another 12 boats were added to the fleet. The Azienda Comunale per la Navigazione Interna (Municipal Company for Inland Navigation) (A.C.N.I.) took over the inland waterboard fleet in 1903 taking control of the 23 vessels the SVL had at the time which was carrying 2860 passengers a day. (ACTV, n.d.) Over time, all the surrounding islands of Venice were added to the routes and diesel powered boats were considered as an option for new versions of the *vaporetti* as early as the 1920s (Playfair, 2021). Since 1933, some parts of Venice's transportation infrastructure have not changed, including the speed at which boats travel through Venice's waters (Smith et al., 2017). On Valentine's Day 1934, a new model of

vaporetti was ordered, the first diesel fleet. These boats became the No42 Annibale Foscari, No43 Spartaco Bello, No44 Alberto Zambon, No45 Franco Gozzi, No46 Ugo Pepe, No47 Severino Francescato, No48 Luigi Passoni, and No49 Antonio Catapan (Playfair, 2021).

In 1941, disaster struck as World War II was still raging on in Europe, and the Venetian ships got requisitioned by the Italian Navy and Army. By the end of the war in 1945, many of the ships in the SVL fleet had been sunk by machine guns (Kimchae, 2012).

After the war, the ACTV, a publicly owned transportation company in Venice, slowly began to buy ships from the SVL. During the period from 1948 to 1990, they began to rebuild the fleet they originally had in Venice. On December 21 1966, the last Mestre human-powered trolley-bus performed its final route (Kimchae, 2012).

Today: Overview of transportation in Venice

There are several aspects of the current-day transportation system in Venice, including the boats themselves, other types of vehicles, different types of tickets and passes, and the companies that operate all of these systems. In what follows, we discuss the various aspects of transportation in Venice, especially those used by commuters moving between the historic city and the mainland and the problems with today's transportation systems.

Figure 10: Ways to get in and out of the historic city of Venice

In order to enter or leave the historic city of Venice, travelers can either take a boat or cross the Ponte della Libertà via train, bus, car, or tram (see Figure 10). Once in the historic city, there are a few transportation hubs located in Cannaregio and Santa Croce:

Figure 11: Location of transportation hubs in historic city of Venice

Trains

One way to get from the mainland to the historic city is by train. The Santa Lucia train station (also called *Ferrovia*), located in Cannaregio along the *Canal Grande* (Agency, R. W., n.d.), is next to a water bus stop, making it a convenient destination for residents of the historic city (ItaliaRail, n.d.). For a resident of the historic city to commute from Santa Lucia to the train station in Mestre costs 1,40 € and takes 10-11 minutes. The train runs every 5-10 minutes from Stazione di Santa Lucia to Mestre, both on weekdays and weekends. From the Mestre station, the train provides access to many other Italian cities within Veneto and the rest of the country (Trenitalia, n.d.). Every day, 371 trains arrive at *Ferrovia* and 378 trains depart from the station (Rete Ferroviaria Italiana, n.d.).

Buses

Multiple companies, including ACTV, ATVO, and others, operate buses throughout Venice and the Veneto region. Commuters can take a bus leaving from Piazzale Roma across the *Ponte della Libertà* to a number of locations on mainland Venice.

ACTV operates 110 bus routes throughout Venice and its suburbs, including 48 lines in Urban Mestre (including 5 Night lines and 2 School lines), 8 lines in the Chioggia network, 8 lines in the Lido network (including 1 Night line), and 46 lines in the suburban network (including 4 school lines). As of 2010, they were using 620 buses to operate these lines, 100 of which were on Lido. Newly purchased buses are equipped with accessibility features such as ramps and reserved seating. ACTV buses traveled a total of 33.5 million km in 2010.

ATVO operates 70 routes throughout eastern Veneto, and are classified by type of operation, rather than location: there are General lines, Carrier lines, Airport lines, Summer lines, and ‘Quickly’ lines (shortcuts from various cities to Punta Sabbioni). They use 311 buses, which have varying levels of accessibility features. All of the buses used for their Urban Service are considered ‘accessible,’ but the same applies for only 37% of the buses used on the Extra-Urban service, and 19% of those used for rentals and for school buses. They traveled a total of 14,121,626 km in 2019, including subcontracting (13,324,257.30 km), school services (510,862.90 km), and rental services (899,270 km).

Trams

Additionally, the ACTV operates trams (ACTV, n.d.). These are electric land-based vehicles that move along a track laid in streets (Encyclopedia Britannica, n.d.). There are two tram lines in Venice: T1 and T2 (see Figure 12), which mainly operate on the mainland, although there is a stop in Piazzale Roma. The timetables are different in the summer and winter: from April through October, they run 07:00 through 23:00 on weekdays and 08:00 through 22:00 on weekends, and from November through March, they run 07:00 through 23:00 on the weekdays and 08:30 through 21:00 on weekends (ACTV, n.d.).

Figure 12: ACTV tram lines (ACTV, n.d.)

The tram started its operations in 2010 in Mestre, Marghera, and Favaro. In 2015, the stop in Piazzale Roma was added, forming a connection to the historic city of Venice (ACTV, n.d.).

People Mover

The ACTV People Mover service is a short cable car line with only three stops at major transportation hubs: Tronchetto, Stazione Marittima, and Piazzale Roma. According to ACTV, it only takes 4 minutes to reach Piazzale Roma from Tronchetto using the People Mover, and 3200 people use the service every hour. Every 7 minutes, the People Mover leaves from either terminus. From April through October, it operates from 07:00 through 23:00 on weekdays and from 08:00 through 22:00 on weekends. From November through March, it operates from 07:00 through 23:00 on weekdays and from 08:30 through 21:00 on weekends (ACTV, n.d.).

Car parking

Car owners can drive their car across the Ponte della Libertà into the historic city. They can also drive on Lido di Venezia (Lido di Venezia, n.d.). However, there are no cars in the historic city itself as there is no room for roads that could sustain cars. Instead, visitors bringing a car from the mainland must park it at one of the parking facilities in Santa Croce (or at San Giuliano, which is located on the mainland). The Municipal Parking Garage, San Andrea, and San Giuliano are operated by ACTV. Details about the car parking facilities are in Table 1. Drivers can also get a monthly pass for ACTV garages for 60 €/month. There is also a caravan park, which is outdoors to accommodate motorhomes and campers for up to 48 hours (ACTV, n.d.).

Table 1: Parking facilities (ACTV, n.d.) and (Tronchetto, n.d.) and (Personal Communication, Fabio Carrera, December 2022)

Parking facility	**Car spaces**	**Motorcycle spaces**	**Accessible spaces**[1]	**Price**	**Hours**
Tronchetto	3957	60	33	22 € for 24h	24h/day, everyday
Municipal Parking Garage	2182	300	14	35 € for 24h, 15 € overnight	24h/day, everyday
San Andrea	100	0	2	7 € per 2h	24h/day, everyday

[1] At all of these parking facilities, customers with disabilities can park in these reserved spaces for a reduced or free rate

San Giuliano	615	5	18	First 3 hours free, 2 € for 4h, 4,50 € for 5h, 8 € for 6h, 12 € for over 6h	06:00 - 02:00
San Marco	900	N/A	N/A	€ 45 for 24h € 18 overnight	24h/day, everyday
Parcheggio Doge	45	N/A	N/A	€ 4,5 for 1h Maximum € 45	07:00 - 01:00
Aree Portuali	1000 (estimated)	N/A	N/A	N/A	N/A

Ferry Boats

Car owners can bring their cars to Lido via Ferry Boats (see Figure 13), which are operated by ACTV. Approximately 70 cars can fit on one Ferry Boat (Penzo, n.d.), but there are often larger vehicles on the boats as well, such as buses carrying passengers and/or trucks carrying cargo. This is because the two routes that Ferry Boats travel, Line 11 and Line 17, are both Integrated Mobility lines that carry passenger buses over water via Ferry Boat.

Figure 13: An ACTV Ferry Boat in the Giudecca canal

Tickets are purchasable by single ticket or annual pass for those who do not live or work on Lido or Pellestrina. Prices start at € 8, but vary by which routes are available using the ticket and the size of the vehicle. Those who live or work in Lido or Pellestrina can also purchase passes worth 10 or 40 tickets. They can also purchase passes for 10 trips combining a trip on Line 11 and Line 17. All of the available ticket prices can be found in Tables 7-9. The ticket prices do not include the driver or passenger of any vehicle. There are two ferry boat lines run by ACTV: Line 11 runs from Alberoni (Lido) to Santa Maria del Mare (Pellestrina) and vice versa, and Line 17 runs from Tronchetto to Lido S.Nicolò (ACTV, n.d.). A trip from Tronchetto to Lido S.Nicolò lasts 35 minutes.

There are currently seven different Ferry Boats in operation: the Ammiana, Pellestrina, and S. Marco are typically used on Line 11, and the Marco Polo, San Nicolò, Metamauco, and Lido of Venice are typically used on line 17 (ACTV, n.d.).

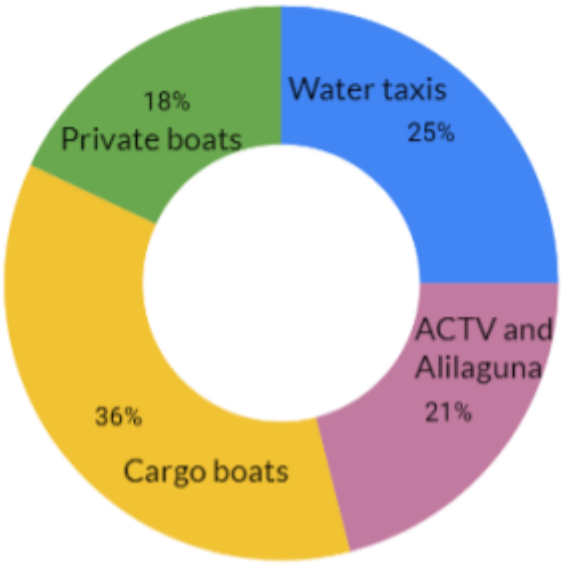


Figure 14: Boat traffic by sector (Adapted from (Pauwels Jasinski, Gonclaves, & Tedesco, 2016)

Alilaguna

Alilaguna, on the other hand, operates *imbarcazioni* on five different routes that connect distant locations within the city of Venice. Users can take Alilaguna lines to and from the airport, mainland, Lido di Venezia, Murano, and the historic city (Alilaguna, n.d.). The red, orange and blue lines connect the historic city, Lido di Venezia, Murano, and the Marco Polo Airport. The red line is seasonal, running from April through October. Alilaguna also operates the Green and Pink "tourist lines", which stop at locations that tourists are interested in, such as Murano, Burano, Torcello, and Mestre (Alilaguna, n.d.). There are two main types of tickets purchasable for Alilaguna trips: timed tickets, which allow unlimited travel within a certain time period, and standard tickets, which allow travel within the locations specified by the ticket type. Alilaguna also offers a tour of the city, including Murano, Burano, and Torcello, for € 25. Alilaguna traffic combined with ACTV boat traffic consists of 21% of the boats present in the canals.

ACTV

The publicly-owned company *Azienda Veneziana della Mobilità* (AVM), or Venetian Mobility Agency, is responsible for implementing the policies surrounding mobility set by the City of Venice throughout the Comune di Venezia. It has two subsidiaries. The *Azienda del Consorzio Trasporti Veneziano* (ACTV), or Venice Public Transport Company, operates several modes of transportation within the Comune di Venezia. The other AVM subsidiary, Vela, is responsible for organizing many of the city's traditional events as well as operations of transportation ticket sales (see Figure 15).

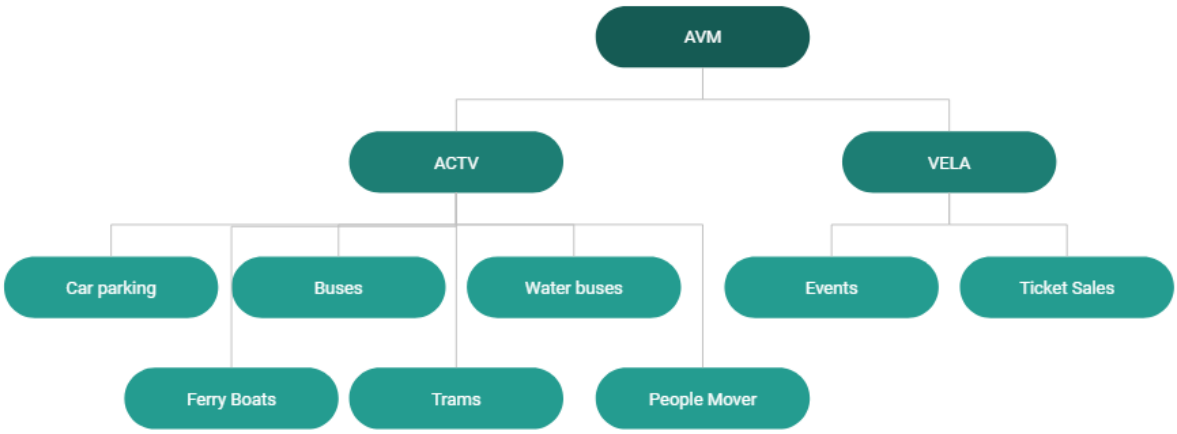


Figure 15: Transportation systems operated by AVM subsidiaries (Adapted from ACTV, n.d.)

Tickets for transportation operated by ACTV (*vaporetti*, buses, trams, People Mover, and ferry boats) can be purchased by a few different means. There are *Venezia Unica* agencies located throughout the city, including Lido, Mestre, Chioggia, Marco Polo airport, and key transport hubs in the historic city such as Piazzale Roma, Ferrovia Santa Lucia, and Tronchetto (Venezia Unica, n.d.). There are also authorized dealers located throughout the city as well as automatic ticket machines at many *vaporetto* stops. Additionally, tickets are purchasable through the AVM Venezia Official app. These tickets cannot be transferred to a *Venezia Unica* card or to another mobile device. When entering any mode of transportation operated by ACTV, a user must validate their ticket or pass at a ticket validating machine near the entrance to board the transportation (ACTV, n.d.).

Since its inception, ACTV has continued to evolve over time. The same can be said of the city of Venice and its canal system. Many of the important changes to the canals, ACTV, and other major transport agencies can be seen in Figure 16 and are expanded in the sections that follow.

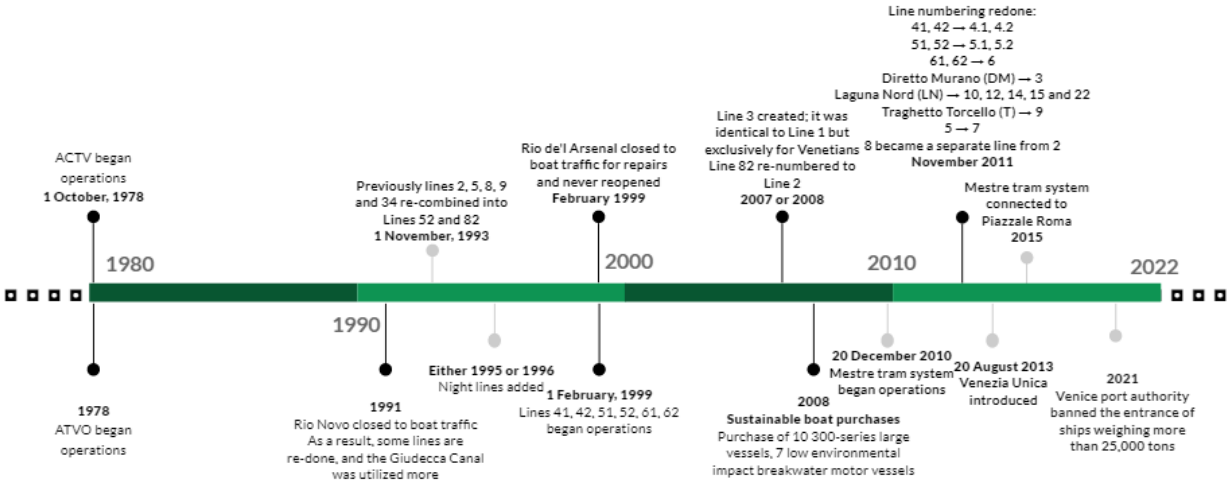


Figure 16: Major changes to the transportation systems in Venice that shaped today's system (Adapted from Personal Communication, Paolo Corposanto, 2022)

The recent history of ACTV and its route changes demonstrate how the City of Venice has adapted over time to protect the historic infrastructure and improve transportation time and convenience. Highlighted on the timeline are changes made to the lines today known as 1, 2, 3, 4.1, 4.2, 5.1, 5.2, and 6. Line 1 moves through the center of the city, and hasn't changed since it began as the Linea Canal Grande under ACNIL. Line 2 (previously 82) was created to be a faster, more efficient way to get to the most commonly used stops on Line 1, as it follows nearly the same route, but skips the lesser-used stops. The Former Line 3 (which is similar to today's Line 2) was similar to Line 1 but could only be used by Venetians, based on residency; it was an attempt at improving convenience for the city's residents. Line 3 was created as a "Direct" route to Murano (hence its former name, Diretto Murano). Lines 4.1, 4.2, 5.1, and 5.2 (formerly 41, 42, 51, and 52) are circular lines that traverse nearly the entire historic city, which was a change made to improve convenience (Personal Communication, Paolo Corposanto, 2022).

In 2015, the tram lines that had previously operated in Mestre-Marghera-Favaro expanded into the historic city of Venice by adding a stop in Piazzale Roma. This demonstrates an effort to expand the possible commuting region by making it faster and more convenient for residents of the historic city to get to nearby areas of the mainland (Personal Communication, Paolo Corposanto, 2022).

In 2021, the Venice Port Authority banned the entrance of ships weighing over 25,000 tons, which are typically cruise ships. This was done because of environmental concerns after Unesco issued a warning that Venice was at risk of being put on the world heritage endangered list unless large ships were banned from the city (Giuffrida, 2022).

Venezia Unica

Many residents, commuters, and others who are in Venice long-term purchase *Venezia Unica* cards. The card can last up to 5 years and is renewable at expiration (ACTV, n.d.). It is intended for use by residents and anyone else who will be in Venice long-term, such as students or long-term tourists. Although it costs €10 to activate the card, there are varying prices for different populations to enable the card (giving it the ability to hold tickets), ranging from €0 for residents of the Municipality of Venice to € 90 for those who live outside of the Veneto region (ACTV, n.d.). Purchasing the card allows for the purchase of a monthly pass. The most typical monthly pass can be used in the Municipality of Venice networks (excluding lines 16 and 19 and the Casinò line), mainland bus network (including trips to or from Marco Polo airport), on Lido and Pellestrina, and tram and People Mover networks. It costs € 37,00 for a month or € 370,00 for a year of access. This and all of the other types of monthly and annual passes have a student discount for students between the ages of 6 and 25. For those who opt to purchase individual tickets (which give the same travel access for 75 minutes from first validation), the price is €9,50 for those who do not hold a *Venezia Unica* card or € 1,50 for those who do. The card provides a large discount on almost all ticket types.

Water buses

The water buses are one of the principal transportation systems in the historic city of Venice. A water bus is a boat which functions much like a bus in typical cities, bringing people along set routes throughout the city and making frequent stops. There are two types of boats used for most of the routes within the historic city: *vaporetti* (see Figure 17) and *motoscafi* (see Figure 18). The *vaporetti* are used on Lines 1, 2, 7, 13, and the Night lines, and they can carry 215-230 people at once. Therefore, on Line 1, up to 1150 passengers can be carried per hour. The *motoscafi* are used on Lines 3, 4.1, 4.2, 5.1, 5.2, and 6, as

these routes pass underneath shorter bridges and thus require smaller boats. The *motoscafi* can carry 150 passengers.

Figure 17: A *vaporetto*

Figure 18: A *motoscafo*

There are stops throughout the historic city, as well as in Lido, Murano, and other surrounding islands (see Figure 19). There are 23 daytime lines (which operate from approximately 05:00 to 23:00 every day), as well as 3 Night lines (which operate from 23:00 to 05:00). Many of the lines move back and forth (in both directions) from one end of their route to the other, while some move in a continuous loop. There are two lines (8 and 18) which only operate during peak tourist season (May through September) to relieve congestion on the other lines.

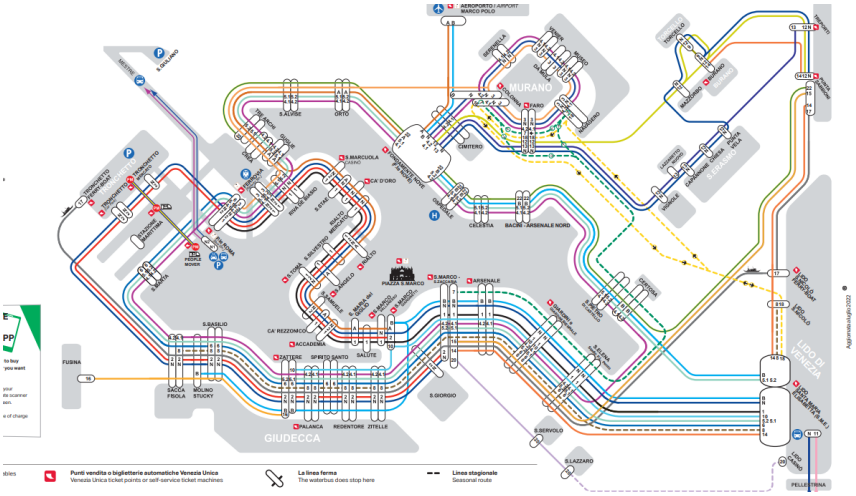


Figure 19: Map of *vaporetto* routes operated by ACTV (ACTV, n.d.)

Private water taxi services

In addition to the publicly-operated water buses and *Alilaguna* transport boats, there are also privately-owned taxi services. The prices are typically higher than using other modes of transportation for the same routes because the taxis are specially requested for the date, time, and pickup and dropoff locations requested by customers, meaning that they're "point-to-point" instead of "lined.". Trips to and from Marco Polo airport typically cost upwards of €100.

The taxis must be licensed. The Comune di Venezia has issued 193 bivalent licenses (including taxi license and rental with driver authorization), 7 bivalent licenses for gondolier cooperatives, and 50 taxi-only licenses (25 of which are for boats equipped with a lifting platform for accessibility), for a total of 250 licensed water taxis (Taxi Acqueo, 2022).

Problems with the current system

Moto ondoso

One problem facing Venice due to the public transportation system is *moto ondoso*, or wake motion. As a motor boat moves through the canals, its spinning propellers create turbulence underwater and on the surface of the water. Part of this turbulence is visible from the surface of the water; however, it all contributes to excessive force on the canal walls. The canal walls were built long before the development of motor boats and at a time when the water level in the lagoon was significantly lower. The lower parts of canal walls (which used to be the only parts exposed to water), as well as building foundations, are traditionally made of Istria stone, which is nonporous and therefore resilient to corrosion by impact force. On the other hand, much of the construction on top of stone, and the walls of *fondamente* (the streets that are directly next to canals), are made of cheap brick, which is porous. The mechanical force of *moto ondoso* can erode the porous brick and the mortar that seals it to stone. Without proper maintenance and repairs, canal walls can develop large holes and even collapse. Buildings supported by damaged walls can be in danger of collapsing (Chiu, Jaggannath, & Nodine, 2002).

There are conflicting viewpoints on what can be done to stop damage to canal walls. One organization, *Pax in Aqua*, believes that *moto ondoso* needs to be reduced in order to protect the foundations of the city buildings. *Insula*, the company who maintains Venetian canal walls, believe that

there are many factors that lead to canal wall damage and it would be impossible to completely control them. Therefore, they believe that new canal walls need to be designed which are more resistant to *moto ondoso.* The City of Venice has taken some measures to attempt to mitigate the damage. Speed limits have been implemented throughout the historic city (see Figure 20). However, there is little evidence that this has been effective. In 2002, a team of student researchers from WPI found that in canals with a speed limit of 5 km/h, the average speed was 12 km/h. They argued that better enforcement of speed limits would reduce *moto ondoso* (Chiu, Jaggannath, & Nodine, 2002).

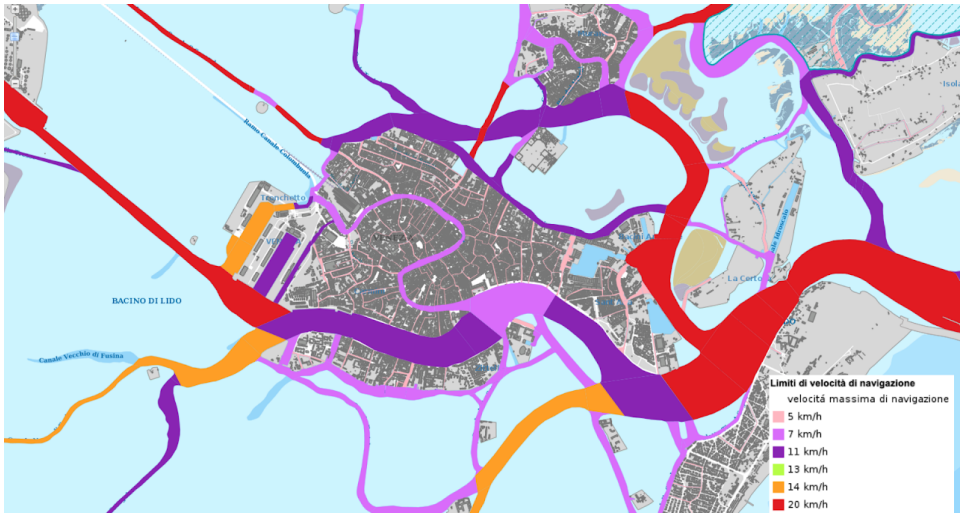


Figure 20: Speed limits throughout the Venetian canal (SerenDPT, n.d.)

Although the mitigation of *moto ondoso* is very important for the future of Venice, the unfortunate side effect of speed limits is that transportation, especially lined transportation that follows speed limits, can be very slow. This is why future modes of transportation that could be brought to Venice might not rely on boats or the canals.

Weather conditions

Like any other city, Venice's mobility is impacted by the weather conditions. Unlike in many cities where snow or windstorms make the most impact, the most pressing weather issues in Venice are fog and flooding. Foggy conditions are very frequent in Venice, with the humidity above 70% throughout the year (Time & Date, n.d.). This causes low visibility and potentially dangerous conditions for boat operations. ACTV limits operations to certain lines if visibility is limited (see Figure 21) (ACTV, n.d.). Furthermore, taxis or privately owned boats might not operate at all in low-visibility conditions (Personal Communication, Fabio Carrera, December 2022).

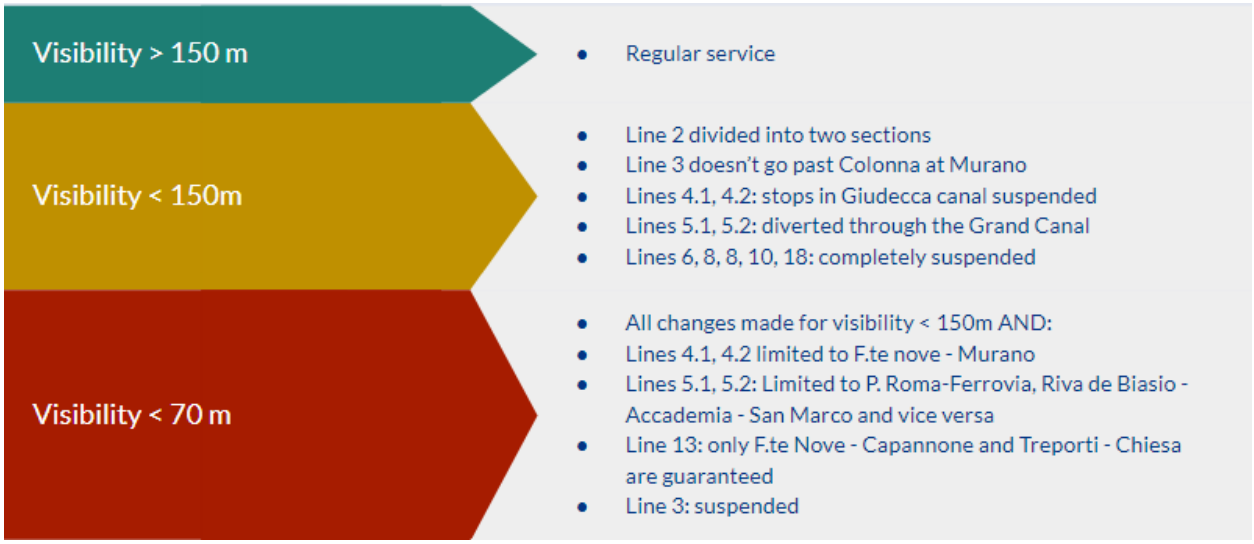


Figure 21: Changes to ACTV *vaporetti* operations based on visibility (Adapted from ACTV, n.d.)

Acqua alta, or high tide, is another weather condition that affects transportation in Venice. Like fog, it affects the ability of all boats to get from the beginning to the end of their journey. ACTV in particular has protocols for re-routing their Lines in the case of various high tide conditions (see Figure 22) (ACTV, n.d.). Typically, tides don't limit the ability to navigate, but do limit the ability of boats to go under bridges based on the height of the bridge and the height of the boat. Therefore, instead of cancellations, it's more frequent that ACTV re-routes Lines. In particular, a lot of the circular lines (such as 4.1, 4.2, 5.1, 5.2) are split into linear segments if there's a short bridge in their path.

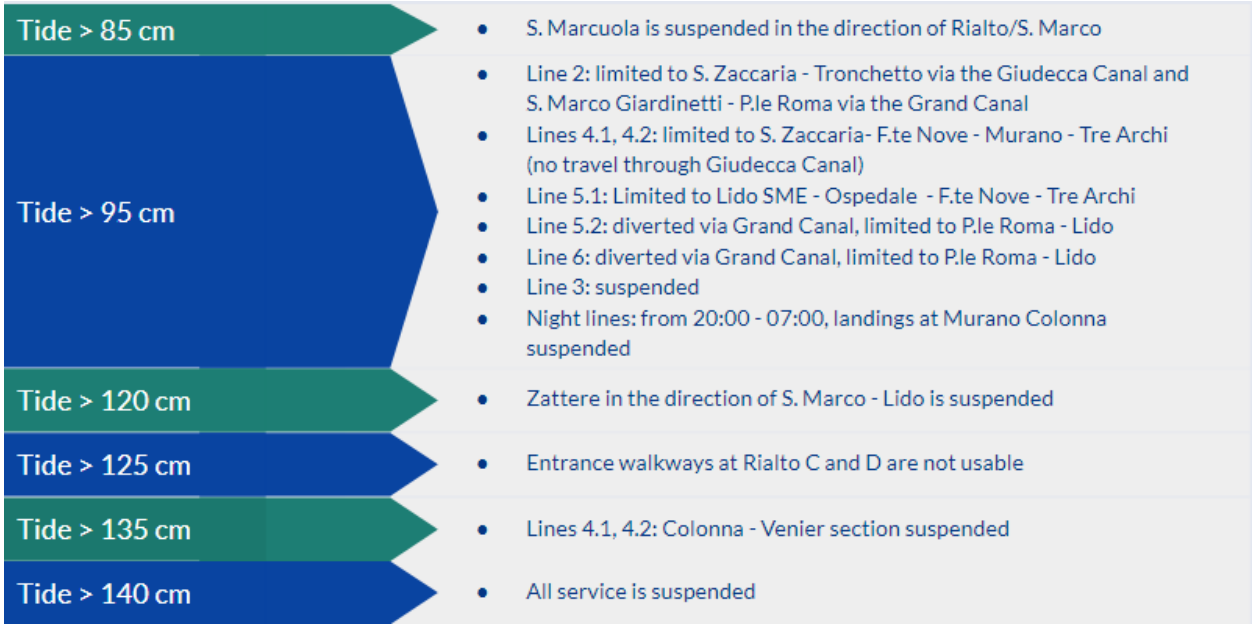


Figure 22: Changes to ACTV *vaporetti* operations based on tide height (Adapted from ACTV, n.d.)

Crowded canals

In 2015, a group of student researchers from WPI found that the ACTV *vaporetti* and Alilaguna boats made up a combined 21% of the boats in the Venetian lagoon. The cargo boats make up 36% of boat traffic, and taxi boats account for 25% of the total boats (Pauwels Jasinski, Gonclaves, & Tedesco, 2016). The remainder of boats in Venice are privately owned and operated. In totality, there are a lot of boats in the Venetian canals – debatably, too many. At times, boats cannot dock or drop off and pick up passengers because they have to wait for another boat to get out of the way, or boats may have to make sharp turns or move slower than they could in order to avoid collisions with other boats. Sometimes, it's not avoidable: collisions between various types of boats have been reported (ANSA, 2018).

There are several opportunities to reduce the number of boats and increase the efficiency of the boats that are moving throughout the canals. For example, taxi boats' cabins are empty during 33% of their operating time. A ride sharing system could reduce this so that the boats are more efficient and not causing undue *moto ondoso* without any passengers (Pauwels Jasinski, Gonclaves, & Tedesco, 2016). Additionally, a group of WPI students in 2001 proposed a system that would have improved the efficiency of the cargo delivery system in Venice, which would have had a similar effect of reducing the number of boats and useless trips made by those boats. Their proposal would have organized cargo boats to deliver cargo *by location* (with mixed products all for locations near each other) instead of *by product* (where they carry a single product and have to distribute it to many locations throughout the city) (Bender, Duffy, Gagliardi, & Tucker, 2001).

Faster ways in and out of Venice: previous proposals to improve the transportation system

Given all of the problems with today's transportation system in Venice, it isn't surprising that many citizens, town councils, and engineers have taken it upon themselves over the past several decades to suggest better means for transportation in the historic city. Especially during the twentieth century, there have been several proposals for new transportation systems in the historic city of Venice, but none have come to fruition.

1911 Multimodal Proposal

In 1911, a proposal was published with the goal of connecting the historic city of Venice, Campalto, Mestre, Murano, Lido, Pellestrina, and Chioggia (see Figure 23). Starting on Mestre, Ing. Daniele Donghi proposed a train bridge in the same place that the train bridge exists today. They also proposed a parallel tram bridge, which likely would have connected to the mainland at San Giuliano. Then, a pedestrian bridge would have started on Fondamente Nove and gone across Cimitero and Murano before arriving at Campalto (just south of Favaro, where the Marco Polo airport was later built). There was also meant to be a connection between Sant'Elena and Lido Santa Maria Elisabetta, but there were three options listed for how this could be achieved: jetties extending some of the way with boat shuttles navigating between them,

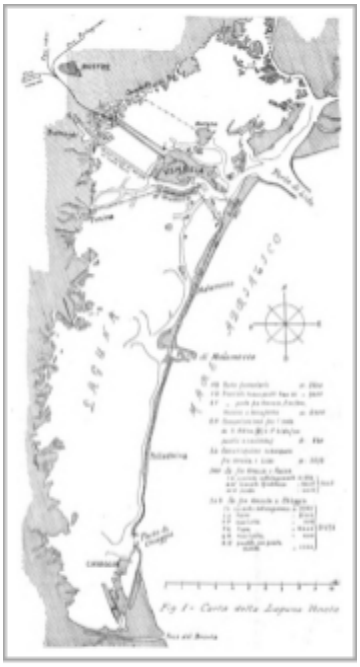


Figure 23: 1911 proposal to increase connection throughout the Venetian lagoon (Donghi, 1911)

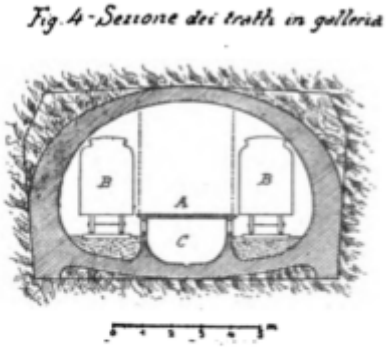


Figure 25: Cross section of the tunnel that was suggested to connect San Marco/San Zaccaria with Quattro Fontane (Donghi, 1911)

two jetties extending on either end with an underground passageway between them, or an underground passage the entire length of the route. It's unclear if the underground passage would have been a *sublagunare* or for pedestrians. There was also proposed to be a connection between San Marco/San Zaccaria and Lido Quattro Fontane, which would have been an underwater connection (see Figure 24). There also would have been an underwater passage, of unspecified means of transport, between San Marco/San Zaccaria and San Giorgio (on Giudecca), and one from the western end of Giudecca to San Giorgio. Then, a bridge would have connected the western end of Giudecca to Fusina on the mainland. In order to connect the historic city to Chioggia, a series of trams and boat shuttles was suggested following the islands of Lido and Pellestrina: there would have been a tram from Quattro Fontane to the southern tip of Lido, then a boat shuttle to the northern tip of Pellestrina, then another tram to the southern tip of Pellestrina, a boat shuttle to Sottomarina (near Chioggia), and then a route to Chioggia with jetties on either side and a mobile bridge to allow boats to move across its path (Donghi, 1911).

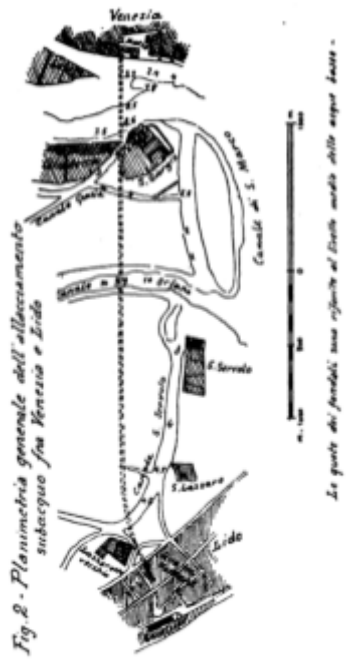


Figure 24: The route of the proposed *sublagunare* from 1911 (Donghi)

The underwater passage between San Marco/San Zaccaria and Quattro Fontane is interesting as it mirrors some of the more recent *sublagunare* proposals for new transportation in Venice. It would have included an underwater tunnel with two electric trams in either direction and a pedestrian passage in the middle (see Figure 25) (Donghi, 1911)

1933 *Sublagunare* Proposal

In 1933, Ing. Miozzi published his proposal to connect Venice to the mainland (see Figure 26). Some of the same routes and key station locations from the 1911 proposal are reflected in this proposal as well, including Mestre, Giudecca, Lido, Pellestrina, and Chioggia. This proposal consisted of a single *sublagunare* route from Mestre to the historic city of Venice (including stops in Ferrovia, western Giudecca, stops on central and southern Lido, Pellestrina, and Chioggia (Novello, 2020).

Figure 26: 1933 *sublagunare* proposal (Novello, 2020)

1959 Certosa Highway Proposal

In 1959, a Town Plan culminated in a plan for a motor road (see Figure 27). Part of the highway would have been underground. The route would have followed Ponte della Libertà, but then instead of going south into the area where parking is located today, the cars would have gone north and followed Fondamente Nove. Then, they would have followed a proposed route across the lagoon onto Punta Sabbioni and Treporti. This plan was controversial, gaining opposition from nonprofit *Italia Nostra*, who proposed a New Town Plan of Greater Venice Italia Nostra that did not include the Certosa Highway (Bellavitis, 1986).

Figure 27: 1959 Town Plan for a highway (Bellavitis, 1986)

1990 People Mover proposal

In 1990, the Consorzio Trasporti Veneziano published a proposal for a People Mover (see Figure 28). The proposal consisted of two tram lines on the mainland. The yellow line starts in Oriago, continues to Mestre, and ends at Tessera and the Marco Polo Airport. The orange line starts in Chirignago, goes through Mestre, and continues to the historic city. As the tram moved into the lagoon, it would have become a *sublagunare* and continued through the historic city, with stops at Tronchetto, Stazione Marittima, Piazzale Roma, Ca' Foscari, Salute, San Zaccaria, Arsenale, Giardini, Sant'Elena, Santa Maria Elisabetta, Gran Viale, Spiagge, and Casinò. The locations chosen for stations reflects the fact that the authors are transportation engineers, and chose locations based on the locations of other transportation hubs (Tronchetto, Stazione Marittima, and Piazzale Roma), and population hubs.

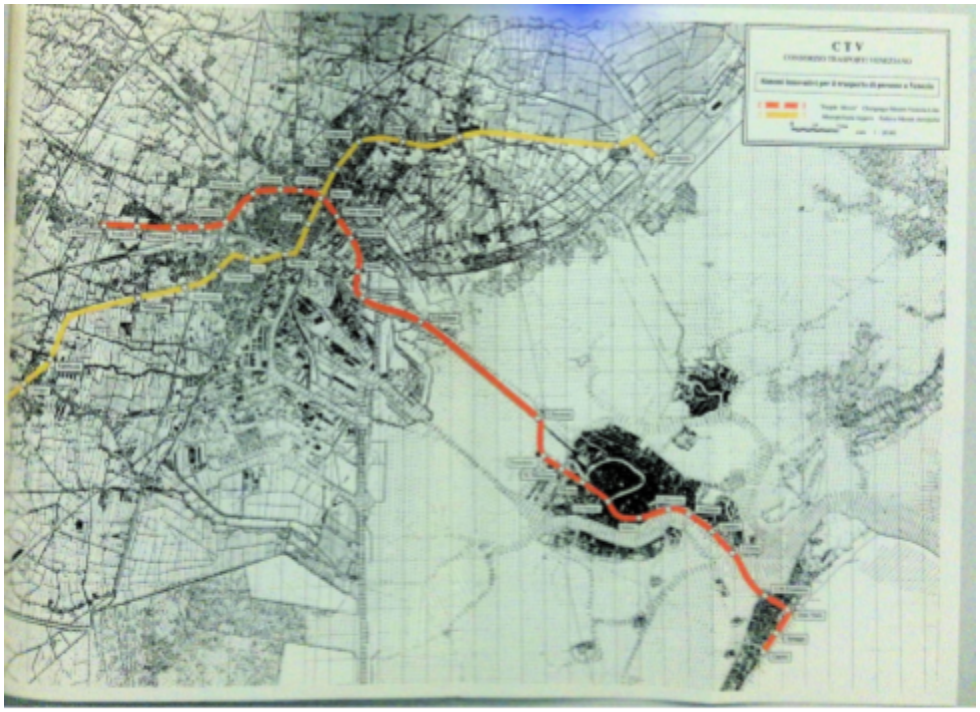


Figure 28: 1990 People Mover proposal (Battista & Fiorin, 1990)

2005 *Sublagunare* Proposal

In 2005, the Mayor of Venice, Paolo Costa, proposed a *sublagunare* that would have connected Venice to the Marco Polo airport. It consisted of one line with stops at the Marco Polo airport, Tessera, Murano San Mattia, southern Murano, the western end of Fondamenta Nove, Ospedale, and Arsenale Nord (Smith, Cody, Bonina, & Panicci, 2017). It would have taken only fourteen minutes to traverse the entire five-mile route. The City of Venice had committed to funding 56% of the cost, but it didn't end up being constructed (Sylvers, 2005).

2017 *Sublagunare* Proposal

Most recently, in 2017, a group of student researchers from WPI proposed an extension to the 2005 *sublagunare* proposal that would have improved connection across the lagoon (see Figure 29). Their alternate route had stations located at Lido Santa Maria Elisabetta, San Zaccaria, Palanca/Zattere (with a pedestrian bridge between the two), Ferrovia/Piazzale Roma (with pedestrian access to both), central Mestre, and the Marco Polo airport.

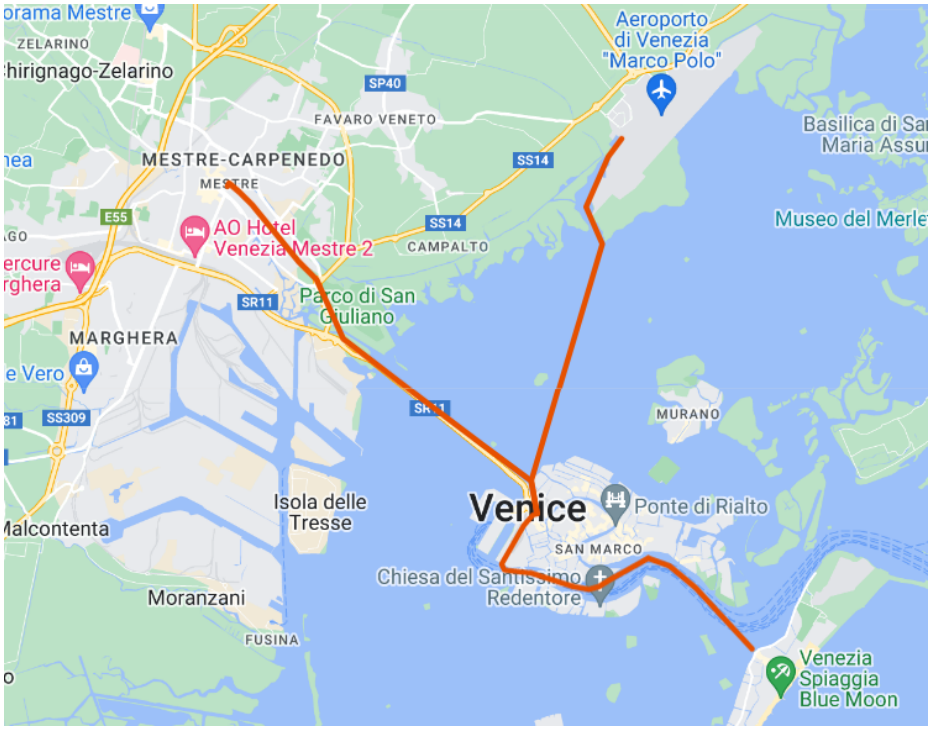


Figure 29: 2017 *sublagunare* proposal from WPI student researchers

2022 *Sublagunare* Proposal

In 2022, Raul Villalobos, another student researcher from WPI, proposed a *sublagunare* with the goal of decreasing commute times and thus increasing the job market for Venetians (see Figure 30). The proposal has three phases in order to prioritize connectivity between different areas of the city. The first phase has four stops (stops with two indicated locations stop between the two locations with an underground pedestrian bridge connecting them): Ferrovia/Piazzale Roma, Palanca/Zattere, San Zaccaria/Giudecca, and Sant'Elena/Lido S.M.E. Once this phase is constructed, residents of Lido near the S.M.E. station would have access to the historic city of Venice's transportation hubs in 12 minutes. This commute pales in comparison to the 31 minute water bus ride between Lido S.M.E. and Piazzale Roma that is possible today (Villalobos, 2022).

The second phase of this proposal extends the first line by connecting Lido to the Marco Polo airport via Ospedale/F.te Nove and Murano Colonna. Today, there are several ways to get to the airport from the historic city of Venice, including Alilaguna boats, ACTV water buses, and buses on the mainland. From Lido, the fastest route is via water bus, taking 1 hour 6 minutes. With the proposed *sublagunare*, the journey would only take 17 minutes (Villalobos, 2022).

Finally, Phase 3 of the plan would connect to mainland Venice at San Giuliano. Located at the end of the Ponte della Libertà, this parking facility has 615 car spots and 18 motorcycle spots.

Figure 30: 2022 *sublagunare* plan. Phase 1 is red, Phase 2 is blue, & Phase 3 is green (Villolobos, 2022)

Since the main purpose of this proposal was to decrease commute times, an analysis was performed of the possible decrease of commute times with the *sublagunare* compared to the current situation. In the present day, Lido is one of the furthest locations in Venice from the mainland. It takes 34 minutes to get to Ferrovia from Lido S.M.E., or even longer from southern Lido. Under the presumption that most commuters don't want to travel more than 60 minutes for work, these commuters only have 25 minutes left of travel on the mainland (see Figure 31).

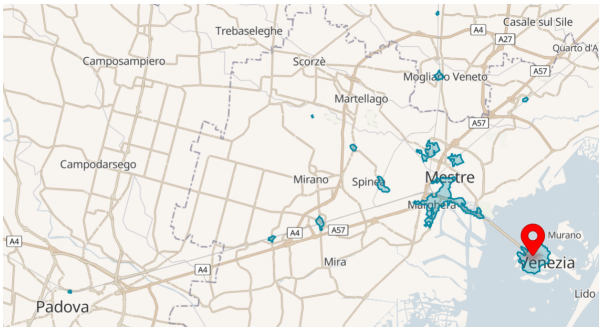


Figure 31: Areas reachable within 25 minutes from Ferrovia using public transit

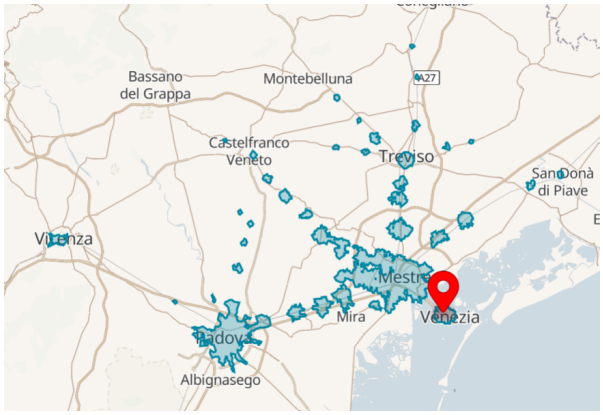


Figure 32: Areas reachable within 50 minutes from Ferrovia using public transit

With the proposed *sublagunare* (Villalobos, 2022), it would only take 11 minutes to get to Ferrovia from Lido S.M.E.. This means that the same commuter who's comfortable with a 1hr commute has 49 minutes to travel on the mainland, and many more available job opportunities (see Figure 32).

In a similar vein, a commuter from the San Marco/San Zaccaria area has a 26 minute water bus trip to Ferrovia today. That means that only 35 minutes of their time is available for travel on the mainland (see Figure 33). With the *sublagunare*, the trip to Ferrovia would take only 8 minutes, so they would have 52 minutes to travel on the mainland (see Figure 34).

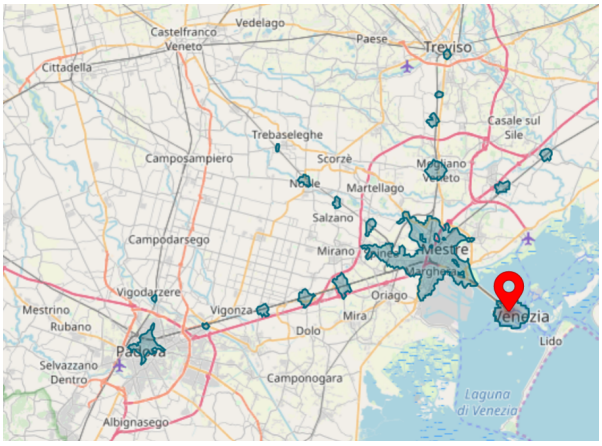


Figure 33: Areas reachable within 35 minutes from Ferrovia using public transit

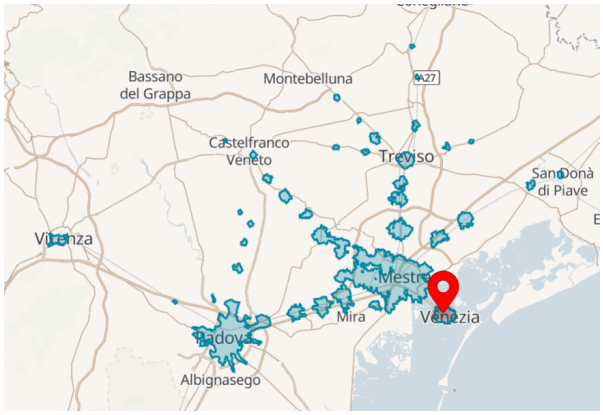


Figure 34: Areas reachable within 50 minutes from Ferrovia using public transit

Finally, for a commuter from Giudecca, the commute to Ferrovia takes 22 minutes today, leaving 40 minutes for travel on the mainland (see Figure 35). With the *sublagunare*, it would only take 5 minutes to arrive to Ferrovia, so 55 minutes are available for travel on the mainland (see Figure 36).

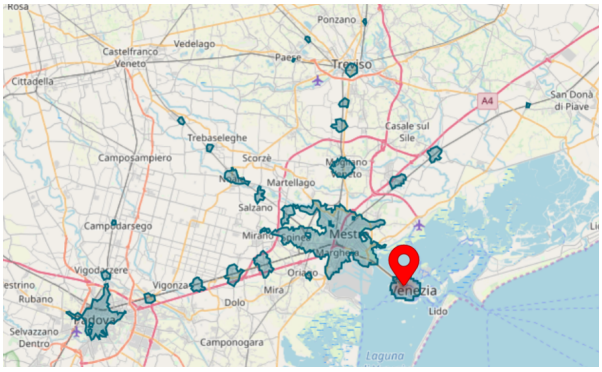


Figure 35: Area reachable within 40 minutes from Ferrovia via public transit

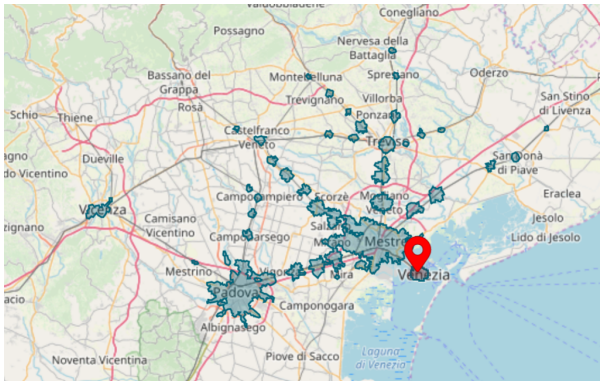


Figure 36: Area reachable within 55 minutes from Ferrovia via public transit

From any of the analyzed locations, it is a lot faster to get to Ferrovia (essentially, access to the mainland) with the proposed *sublagunare* than with the existing transportation systems. Therefore, it can be concluded that the *sublagunare* would expand the job market for Venetians because they will be able to travel to more cities with more job opportunities within the same 1hr or less commute.

Additionally, the *sublagunare* would not cause many of the problems that Venice faces today because of its transportation system. It would be able to function in any weather, as it would not be affected by fog or high tides, especially because it would use driverless trains. Importantly, it would not cause *moto ondoso* on its own. Additionally, because commuters would have the additional option of traveling via *sublagunare*, fewer commuters would travel by any of the existing boat transport systems, causing less *moto ondoso* overall than there is today. This would reduce crowding in the canals as well, improving safety for travelers.

Conclusion

Since its founding, Venice has adapted to many challenges and technological advances. For many decades, it kept up with the rest of the world: steam boats came to Venice not long after the first steam boat in the world, and the car bridge to the historic city was built not long after the world's first car patent. However, Venice has not kept up with advances in transportation more recently. A *sublagunare* would reduce the effects of many of the issues facing the city today due to its transportation systems, and would expand the available job market, improving the quality of life for Venetians who are stuck with either low-paying jobs near home or a long commute.

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