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Sustainable Inland Waterway Transportation Systems: Framework Proposal

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Abstract
Large cities are widely recognized as major contributors to climate change due to their high energy demand and heavy reliance on on-road transportation. Urban mobility today brings additional concerns about predicted demands arising from people's necessities of living in cities and their respective needs to travel in different forms, either for personal or professional purposes. This study based on a literature review and case studies analysis proposes a framework to support the implementation of Sustainable Inland Waterway Transportation Systems as an alternative to road transport. The proposed framework is tested in São Paulo City (Brazil).
In the implementation of a sustainable inland waterway transportation system, the following factors were identified as strategic: user characteristics and behaviour, operators' characteristics and behaviour, investment in infrastructures, regulation and taxation, and Government. Infrastructure and strategic planning are areas that deserve further investigation. Research could focus on developing strategies for efficient routing, taking into account various potential limitations, water navigability, vessel capacity, traffic management, and transshipment locations. Intermodality between different transport modes is a crucial area that needs to be addressed to ensure full integration into the multimodal network. Investigating connectivity and information sharing systems between modes would enhance the overall efficiency and attractiveness of waterway transportation in the city's ecosystem.

Keywords: transportation, waterway, framework, sustainability, case studies.

1. Introduction

Over the last decades, climate change has been taken to the top of political and environmental organizations' discussions, working on promoting and creating awareness among worldwide communities, to make needed adaptions to save the future of actual and future generations (Banister, 2011). Urbanization, considered by many as the main propulsor for climatic changes, "refers to the concentration of the rural population and non-agricultural production factors in cities and the transformation of rural areas to urban areas" (Liu, Dong , Wang, Zhang, & Liu, 2021, p. 4). As urbanization continues, the climate is facing more pressure due to the arrival of people into cities (Hendrickx & Breemersch, 2012). Urban mobility today brings additional concerns about predicted demands arising from people's necessities of living in cities and their respective needs to travel in different forms, either for personal or professional purposes. Usually, most of these travels are fueled by carbon, which leads to increased carbon emissions affecting the global climate. With the exponential increase in the number of inhabitants in big cities, there is a need for better mobility planning in urban centers, by exploring various methods

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for maintaining efficient movement of people and goods, competitiveness, and agility in all processes. The current situation is evidently not sustainable, and it is imperative for the transportation sector to make a significant contribution towards achieving carbon reduction targets (Banister, 2011).

To achieve sustainable urban transport policies, it is crucial to implement energy-efficient solutions that promote low-carbon initiatives, such as greener and smarter local transport systems. The shift towards zero-carbon transportation modes must be gradual, and existing infrastructures should be leveraged. Road transportation is the most prevalent mode of transport in large cities, and thousands of vehicles use roads every day, contributing to greenhouse gas emissions.

As a result, there is a strong need to transition to sustainable transport modes that can reduce the negative externalities associated with transportation. Recent investments in infrastructures such as rail, underground systems, and river waterways have been observed as cities seek alternative modes of transportation (Cardenas, et al., 2017). The main objective of this study is to conduct a thorough analysis of the primary barriers associated with implementing a sustainable smart mobility alternative utilizing waterways for the transportation of cargo and passengers in the city of São Paulo. By examining these challenges, we would propose a comprehensive framework that effectively addresses these obstacles and offers a sustainable solution for enhancing the efficiency and environmental friendliness of waterway transportation in São Paulo.

This paper is organized in the following way: after the introduction a background about the Inland Waterway Transport is performed, then a methodology section is presented and after that, a framework for Urban Mobility in São Paulo is proposed. Then the results are discussed and conclusions are drawn.

2. Background

There are several works focusing on Inland Waterway Transport (IWT) showing several applications in different geographical contexts. IWT refers to the use of ships to transport goods from origin to transit points by the urban waterway network of a city" (Jan & Nepveu, 2020).

The work of Diziain, Taniguchi and Dablanc (2014) compares intermodal freight transport in Japan and France, with a particular focus on the use of waterborne transport in urban areas. They conclude that in France (Paris) besides it being a minor mode of transportation for both people and freight, IWT is more stable compared to the other modes of transportation. In Japan, the Japanese government has created the Eco-Ship Mark certification for shippers transitioning from road to sea transportation and has made subsidies available to alleviate traffic congestion in major cities. The author suggests the need for stringent government policies to promote sustainable transport alternatives within urban areas. In a recent paper by Trivedi, Jakhar and Sinha (2021), a case study of India was presented, which analyzed the barriers to implementing IWT using a hybrid Multi Criteria Decision-Making model. The objective of this study was to identify correlations among various variables and provide additional insights to policymakers and decision-makers to address critical points and identify measures to overcome them. In their paper, Vilarinho, Liboni, and Siegler (2019) provide insights into the main challenges

and opportunities for using waterways as an alternative to traditional carbon emitting vehicles for mobility. The authors conducted an extensive review of recent research on river logistics and surveyed various stakeholders to validate their findings. Based on their analysis, the authors suggest several actions that can be taken to overcome the barriers identified in their research. Jan and Nepveu (2020) have studied the challenges faced in Amsterdam's historic center with a high flow of tourists and heavy loads which represents a threat to the accessibility and quality of life of residents. In this context, the authors suggest imposing measures to restrict access to heavy-load vehicles and implementing sustainable transportation alternatives to address the issue. With a different focus, Boudhoum, Oztanriseven and Nachtmann (2021) identified the success and failure factors to ensure the effective implementation of IWT, taking into account not only its logistics benefits but also its potential impact on other areas such as flood protection, water supply, hydropower generation, recreation, and the environment. The authors presented a valuation analysis to support investment decisions and an optimization model to maximize the benefits associated with the investment.

In Brazil, the study conducted by Tobias, Ramos, and Rodrigues (2019) provides research based on a preliminary literature review and on-site observations to identify the critical factors for the development of island areas, with a special focus on the integration of different transport modes. The authors propose four dimensions of integration that promote economic and sustainable development, with a particular emphasis on equity and social inclusion. The study concludes that the physical integration of waterway mode is possible, but additional analysis is required to determine its viability.

The utilization of IWT along the Danube River was also studied by Mihic, Golušin, and Mihajlovic (2011) in order to predict the future development of sustainable transport in the region. The authors analyzed the historical evolution of the waterways over the past half-century and examined how these conditions have impacted the use of IWT for the movement of people and goods in Western Europe. Based on their analysis, the authors concluded that the current state of the Danube as a form of conveyance is unsatisfactory and cannot be sustained in the long term. The paper proposes a set of measures that could be taken to improve and promote long-term sustainable development along the Danube River.

The author Janjevic and Ndiaye (2014), focused on the main barriers to the implementation of IWT and the measures taken to overcome them. The author identifies various barriers and proposes corresponding mitigation measures to enhance the effectiveness of IWT. Successful implementation heavily relies on intermodal coordination among different stakeholders, and the provision of last-leg delivery services as a crucial factor in improving effectiveness.

Sachs, Azevedo, Dahle, and Henriksen (2021), present a case study of the city and municipality of Stavanger, Norway, in which they describe the implementation of best practices for smart mobility in an urban environment. The authors outline a method for preselecting and evaluating services for a smart mobility hub and provide a clear process for integrating innovative and environmentally friendly vessels into a comprehensive mobility system. The purpose of the study is to share insights into the process of implementing smart mobility practices in an urban context, with a particular focus on the effective integration of new and sustainable transportation modes. The authors Tarkowski

and Puzdrakiewicz, (2021) emphasizes the significance of utilizing small autonomous electric vessels to improve energy efficiency in urban transportation of people and goods, rather than relying on large-scale solutions. The use of autonomous vessels allows for greater integration with existing transportation logistics systems while reducing dependence on them.
More works can be found about IWT in different realities and giving to the field also different contributions (Table 1)

Table 1 – Studies about IWT in different countries and main conclusions

Author	Country where the study was developed	Main conclusions
Mihic, Golušin and Mihajlovic (2011)	Serbia	The use of IWT can be increased through government policies that encourage its adoption. Despite the challenges to be overcome, IWT can be a viable and sustainable option to promote urban mobility and trade in the European region.
Hendrickx and Breemersch (2012)	Belgium	IWT relies heavily on dependable water levels, which are being affected by climate change. An increased risk of water levels can lead to reduced cargo capacity and higher transport costs, and damage to water infrastructure.
Diziain, Taniguchi and Dablanc (2014)	Japan and France	Importance of creating an adequate infrastructure and the required significant investments, concluding that rail and river transport are promising solutions for the countries' urban logistics.
Gołębiowski (2016)	Poland	Exploiting the potential of IWT would support reducing roadway congestion and improving the city´s logistic performance. It is mentioned the initiatives realized by local authorities to support and develop IWT, such as the creation of National Program for the development of IWT, and the establishment of a dedicated agency to regulate and promote the sector. Additionally, the authors asked for strict cooperation between public and private stakeholders to get the most from this means of transportation.
Tobias, Ramos and Rodrigues (2019)	Brazil	River transportation integrated with other means of transportation presents itself as a solution for sustainable mobility, reducing the number of cars on the streets, reducing the levels of noise and environmental pollution, and providing social integration for residents in remote regions.
Jan and Nepveu (2020)	Holland	IWT is used for the transportation of perishable food products in the regions of Amsterdam, leading to reducing CO2 emissions and road congestion. There is a need to overcome the lack of infrastructure and the high initial costs for implementation to ensure the success of IWT.

Ydersbond, Auvinen, Tuominen, Fearnley and Aarhaug (2020)	Norway and Finland	Need for collaboration between public and private stakeholders, and the role of local governments in promoting the sector by ensuring the safety and security of users. Some risks are addressed, such as the displacement of traditional transportation modes and the potential for data misuse.
Trivedi, Jakhar and Sinha (2021)	India	Lack of infrastructure, lack of regulation and complex policy environment are the main barriers to implementing IWT in India. Several measures are proposed to promote this means of transportation, including improving infrastructure and simplifying local policies.
Boudhoum, Oztanriseven and Nachtmann (2021)	United States	Model for decision-making in inland waterway infrastructure investments, focusing on the value extracted from this modal. Many elements are mentioned when considering the investment, cost benefit, transport value, risk, and uncertainty factors, as well as environmental and social factors. The author supports his study by listing the benefits of sustainable development as an important variable in decision making.
Sachs, Azevedo, Dahle, and Henriksen (2021)	Norway	Initiatives are undertaken by local authorities to shape intermodality in Stavanger, including the development of Connected Mobility Hub considering integration with cycle and electric vehicles. Some challenges are identified, including a lack of coordination between stakeholders and better data sharing and information exchange.

Attending to Table 1, many works focusing on Inland Waterway Transportation (IWT) highlight the main advantages associated with its use such as a viable and sustainable option to promote urban mobility and trade, creating an adequate infrastructure, river transport is a promising solution for the countries' urban logistics, contributes for reducing roadway congestion, the levels of noise and environmental pollution, and the CO2 emissions and road congestion, creates a positive impact on sustainable development.

Although all these advantages, some barriers are identified such as: water levels, lack of support from local authorities, lack of cooperation between public and private stakeholders, high initial costs for implementation, lack of regulation, complex policy environment in some countries, integration with other modes of transportation, lack of coordination between stakeholders and better data sharing.

According to Banister (2011), cities can greatly benefit from a switch to lowcarbon transportation if the right strategy is implemented, considering the combination of economic, planning, and technological innovations. Therefore, Smart Mobility seeks to address transport-related concerns such as expenditure, travel-time, and gas emissions (Butler, Yigitcanlar, Paz, & Areed, 2022). To minimize greenhouse gas emissions, introducing electric mobility (e-mobility) in cities surrounded by rivers can be an effective solution, also creating opportunities to reduce energy consumption, traffic congestion, and

noise. These technologies can be applied in hybrid or purely electric vehicles that run on solar power, batteries, or hydrogen fuel cells, and can be used for both road and waterway transportation (Dutta, Ankan, & Khan, 2020).

Besides the enormous benefits pointed out in the literature about IWT some challenges also arise. In terms of economic challenges, one primary problem that needs to be addressed to ensure the competitiveness of inland navigation is cost-effective transport. This issue has been addressed by Hendrickx and Breemersch (2012), who noted that the rise of extreme weather periods could trigger a chain of impacts, leading to changes in navigation conditions for inland vessels, decreased cost advantage, and reduced reliability of IWT. In addition, extreme weather events can create critical points that inland vessels must navigate, resulting in reduced load for the entire trip. Hendrickx and Breemersch (2012) emphasize that the main element of economic importance for each ship type (by CEMT class) is the maximum load the ship can carry under specific water level conditions. A lack of sufficient transshipment locations along the canals and space for loading and unloading is further complicating implementation, resulting in time and cost increases for various stakeholders (Montwill, 2019).

In urban centers, commercial shop owners are interested in receiving goods profitably and sustainably, which makes just-in-time deliveries crucial for optimizing inventories and maintaining flexibility while reducing potential costs associated with the negative externalities of freight transport (Cardenas et al., 2017). Therefore, there is a lack of "door-to-door" thinking and awareness among IWT's operators and skills to provide "one-stop-shop" solutions (Hui Lisa & Leung YIP, 2016).

Technical issues have also been identified as an obstacle to the development of IWT. Previous studies have shown that waterways have limitations when compared to roads and railways due mainly to constraints such as infrastructure weaknesses, investment, and institutional weaknesses resulting from governance inefficiencies (Vilarinho, Liboni, & Siegler, 2019).

Inadequate fairway conditions can result in suboptimal load factors, which can lead to increased fuel consumption and emissions per tonne, as well as pose safety risks to navigation and decrease reliability. Moreover, an insufficient network of inland ports and suboptimal spatial planning of logistics and industrial sites may require pre- and endhaulage by trucks, resulting in higher external costs (EC, 2011).

The slow speed of inland navigation presents a significant challenge that may hinder its competitiveness compared to other modes of transport such as road, rail, or air transport. This is particularly relevant when quick delivery of goods is required, as inland navigation may not be able to meet such demand (Gołębiowski, 2016). Additionally, the limited willingness of shippers to entrust their goods to different carriers and the lack of cooperation and organization between carriers and shippers have also been identified as a challenge (Jan & Nepveu, 2020). Moreover, inland waterway transportation, depends on environmental conditions like depth and width of the waterway, streams and their velocity, variation of water levels, radii of bends, maintenance, and equipment of navigational aids (Radmilović, 2005). However, Inland navigation is very competitive with other modes of land transport as the pushed tow of barges can generate more tonne-kilometres per unit distance than any other surface transport mode (Radmilovic and Dragovic, 2007).

It is important for policymakers to consider implementing incentives to encourage the adoption of sustainable practices in the IWT's industry. Previous studies have emphasized the underdevelopment of RIS would cause several limitations in route planning, resulting in more fuel consumption and emissions, no integration with logistics, and resulting in sub-optimal efficiency of transport (higher costs) (EC, 2011).

Low clearances under bridges can pose a challenge to transporting stacked containers on vessels, as mentioned by Gołębiowski (2016). The municipality modified the project's design to incorporate small self-sufficient vessels with either pure electric or hybrid diesel-electric propulsion. When considering the effectiveness of utilizing waterways as a reliable solution in urban environments, climate conditions have been identified as a primary challenge in the literature.

Adaptation to low water levels is a critical concern for the IWT sector, as it has been shown to be the most influential factor for the industry. Effective strategies must be developed to address this issue, as water scarcity and droughts can have severe impacts on various sectors, including agriculture, energy, and industry. According to Hendrickx and Breemersch (2012), while high water levels pose mainly short-term problems for navigation, low water conditions can involve problems for the passage of larger freight ships for longer periods. Additionally, the movement of vessels over water generates pressure differences that can create waves, which, depending on their intensity, can cause shoreline changes.

In terms of governance issues, previous research has identified various stakeholders in IWT. Cooperation among these stakeholders is extremely critical to ensure the effective implementation of the correct strategy for IWT. Environmental agencies, cargo shippers/carriers, port authorities/terminal owners, departments of parks and tourism, utility companies, and local communities (Boudhoum, Oztanriseven, & Nachtmann, 2021), should act together to overcome the main barriers. Given its complexity, there is a clear need for a regulatory authority that can create rules to promote and incentivize synergies between all actors.

Also, the lack of confidence among stakeholders (in this case, carriers and retailers) makes it necessary to inspect all goods delivered in commercial establishments. The social dimension of transport is supported by three fundamental values and principles: equity, accessibility, and mobility (Tobias, Ramos, & Rodrigues, 2019). Equity ensures the fair distribution of transport resources and opportunities, promoting equal access for disadvantaged groups. Accessibility focuses on providing convenient transportation options to individuals regardless of location or circumstances. An intermodal network integrating urban, and IWT can improve accessibility to remote areas, promoting social inclusion (Tobias, Ramos, & Rodrigues, 2019). Mobility facilitates efficient movement, enabling people to reach destinations and participate in social and economic activities. According to the literature review, the main barriers associated with the implementation of IWT are identified in Figure 1.

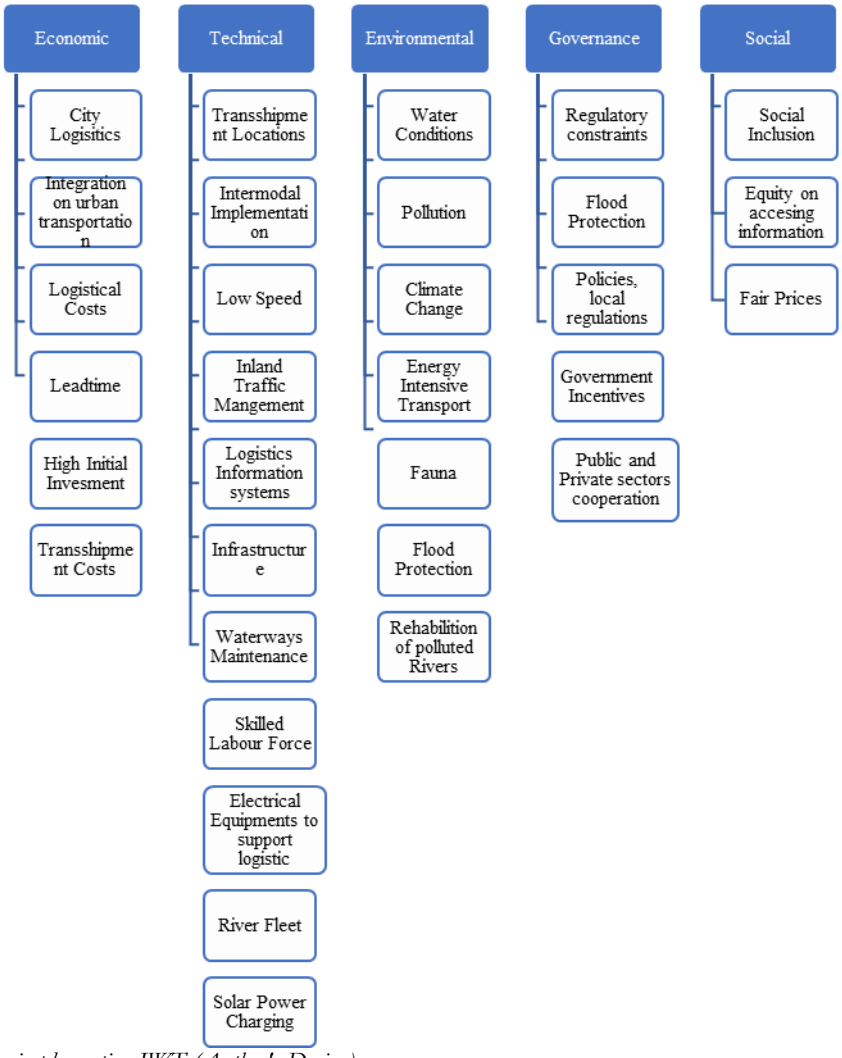

Figure 1. Challenges for implementing IWT (Author's Design)

3. Methodology

The present research emerged from the necessity to evaluate the applicability of energy-efficient waterway solutions to support decreased emissions and increase the efficiency of existing transport modes, while providing an important tool to reduce traffic from overcrowded roadways. The research analyzed data regarding the main transport modes currently used in Brazil, the necessary infrastructure to implement IWT, the effect of climate change on water transportation, environmental conditions, and urban river revitalization plans, as well as the main challenges encountered in similar projects. A narrative research methodology was utilized to conduct this research, with information obtained through a literature review by exploring relevant material from main electronic

databases, considering the research problem. This approach facilitated the creation of a clear overview of the analyzed topic through this approach. The narrative review helped identify gaps in the existing literature, the main challenges, and guidelines to overcome obstacles related to the use of the waterway system as a method of transit in urban centers (Snyder, 2019). The Web of Science database was used to acquire and collect information to support the analysis. This database was chosen because is the most widespread database on different scientific fields which are frequently used for searching the literature (Guz & Rushchitsky, 2009). The literature review covers a spectrum of six years (from 2017 to 2023). The search was conducted using combinations of the following terms: ("mobility" OR "city logistics" OR "urban logistics") AND ("smart" OR "sustainab*" OR "green" OR "low carbon" OR "electrical technologies" OR "low emission") AND ("waterways" OR "Inland" OR "river") AND "barriers". Additional filters were considered to improve the search. Therefore, the sub-areas of "Environmental Sciences", "Green Sustainable Science Technology", "Transportation Science Technology", and "Transportation" were filtered. Similarly, the document type was also considered in the optimization of filtering, with a preference for articles and conference papers. Finally, English and Portuguese were chosen as the languages for the study analysis. Subsequently, by analyzing abstracts, new filters were applied to categorize each document properly according to research questions, reducing the number of articles to approximately 20. After selecting the relevant articles for the discussed topic, a full reading and respective analysis of each document were carried out.

4. Framework Proposal for Urban Mobility in São Paulo

São Paulo, the capital of the state of SP, is the most populous city in Brazil and one of the most populous in the world, with an estimated population of over 12 million 59 inhabitants in the metropolitan area and responsible for approximately 10% of the Brazil´s Gross Domestic Product (GDP) in 2020.

São Paulo and the relationship with City´s Rivers as SP was growing due to the increase in its population, two other rivers became obstacles to the city's growth. They would be the Rivers Tietê and Pinheiros, which also flows into the Tietê River (Ferraz, Abreu, & Scarpelini, 2023). In the early twentieth century, the landscape around the Tietê River and Pinheiros River began to change due to the new waves of immigrants, mainly Italians, and Japanese, who came to settle along the banks of the river. From the 1920s onwards, the capital of SP began to face structural problems such as urban disorder, traffic congestion, difficulty in parking vehicles, irregular housing, and periodic flooding of the Tietê and Pinheiros Rivers.

Roadway transportation is the predominant mode of transportation in Brazil, accounting for over 65% of cargo and passenger transport in the country. This is due to its ease of access and use, which leads to overlap with other modes of transportation. On the other hand, IWT has a small share of responsibility for transport among the most diverse modes, with approximately 14% of the country's goods movements, of which only 0.7% are for cargo transport. Maritime transport represents 9.4% of this percentage, responsible for a considerable amount of the country's trade, and passenger transport accounts for 3% (Estadão, 2022). Although Brazil has an extensive hydrographic network, with 63 thousand

km of rivers, only about 30.9% of this network is used commercially by inland navigation, and only 5% of the cargo movement in the country is carried out by this mode of transport (Transporte C. N., 2019). Regarding inland navigation in the metropolitan region of São Paulo, it is currently almost non-existent, except for small vessels used by the municipality to support dredging and cleaning processes (which will be addressed later). In 2022, São Paulo was responsible for 28.1% of all vehicles licensed in the country, with over 30 million vehicles registered within the state itself. Since São Paulo is the country's main hub and center of commerce, it is common for most of the vehicles produced to travel on the busy streets of the city (Transporte C. N., 2023). The Sao Paulo hydrographic map is illustrated in Figure 2.

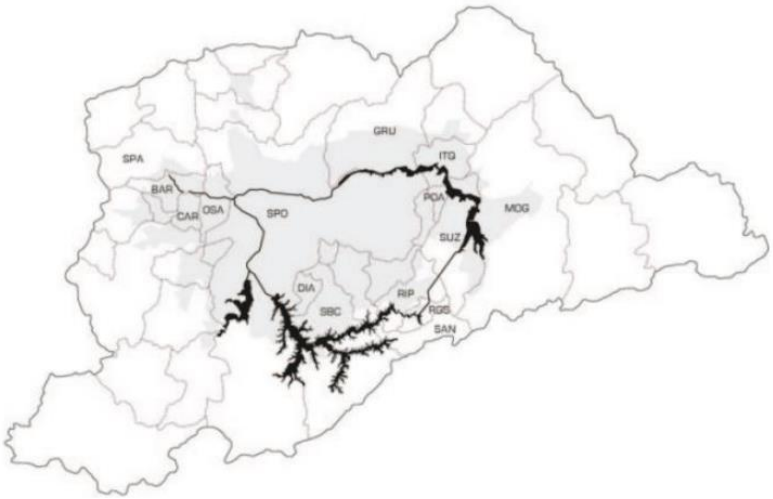

Figure 2 - The Course of Rivers in São Paulo (metropolefluvial.fau.usp.br, 2011).

The main purpose of the framework proposal is to provide a structured and comprehensive approach that can serve as a foundation for investigating the details involved in implementing inland transportation in the city of SP. The framework is intended to facilitate a thorough analysis of the subject matter and to ensure that all relevant aspects are taken into consideration. In developing our framework, we have used as a basis an assessment framework for urban transportation systems (Vilpponen, et al., 2021), which has been proven to be effective in other research studies. By utilizing this tool, we are confident that our framework will be robust and reliable and will provide a solid foundation for our research.

From the literature review, it was possible to identify the freight and passenger transport main stakeholders, pertain both, the private and public levels: public authorities, shippers, freight transport operators, receivers, residents, and owners (Galkin et al., 2019) (Quak, Nesterova, & Kok, 2019) (Cieplińska, 2019). Shippers are considered the main stakeholders responsible for the goods being transported. "Shipper is the person or company who is usually the supplier or owner of commodities shipped" (Galkin et al., 2019). They select the most cost-effective freight operator provider, by ensuring delivering the goods safely to a receiver. Ideally, shippers' locations should be strategically positioned allowing transshipping and bundling goods before transferring between intermodal,

diminishing major impacts on the possibility to introduce various transportation options for urban freight.

Residents are people living in the cities who, in most cases, are the receivers of the parcels that circulate in the congested and polluted urban environment. At the same time, because of the need to travel for professional or personal purposes, they actively contribute to a massive increase in trafficking within urban environments. While on the one hand, they want to receive their goods in the shortest possible time and move faster between places, on the other, they seek a better quality of life from the best sustainability practices at the service of society.

Users and receivers are very important in the process, as they are target groups to receive goods from shippers. They play a crucial role in the success of the IWT sector, as they drive demand for the services and contribute to the economic and social benefits of the sector. Users of IWT include companies that produce and ship goods, such as manufacturers, agricultural producers, and mining companies. Receivers of IWT include companies or organizations that receive the transported goods, such as wholesalers, distributors, retailers, and other end-users (European Commission, 2023).

Owners in IWT are the individuals or companies that own or operate the vessels used for transporting goods or passengers on waterways. These may include companies that specialize in IWT, as well as individual vessel owners who lease or charter their vessels to transport companies (European Commission, 2023). Freight Transport Operators (transporters) are responsible to coordinate the process of consolidation of shipments from different shippers into one truck to get it as close as possible to the full load (Dente & Tavasszy, 2017).

Transport operators play a very important role in the logistic chain, where inter-plant distribution to warehouses, terminals, or sales points is the most common activity among some other operations (Cieplińska, 2019).

Regulator typically is a government or regulatory authority responsible for overseeing and enforcing regulations related to navigation and shipping on inland waterways, it may include shipping companies, port authorities, and trade associations among others (European Commission, 2023). Due to the great diversity of stakeholders involved, the regulation of the waterway sector in Brazil is highly complex. Elaboration of norms, planning, and development of policies, implementation, and maintenance of waterways, regulation of monitoring systems, availability of resources, and financing, are some examples of the most diversified stakeholders involved in the regulation of the sector (Transporte C. N., Aspetos Gerais da Navegação Interior no Brasil, 2019). These same stakeholders were engaged to allow the navigation of Tietê-Paraná Waterway, which connects the metropolitan region of SP to the south of the country, as well as the construction of the São Lourenço Terminal, which enables the transport of cargo by barge to the port of Santos, reducing the dependence on road transport. The improvement of navigation conditions in the city of São Paulo will allow to address environmental concerns such as reducing pollutant gas emissions, car traffic, and road accidents. By revitalizing the rivers, the government also hoped to improve the quality of life for residents by reducing exposure to health risks caused by pollution.

Public authorities play a key role in managing and organizing urban mobility. According to Janjevic and Ndiaye (2014), public authorities have mostly dedicated themselves to

passenger transport in urban environments, focusing on a portfolio of solutions for this purpose. They are responsible for promoting and participating in a wide range of activities, even those carried out in the private sphere, to encourage the implementation of environmentally sustainable measures that improve the quality of life of citizens. Moreover, local authorities are responsible to engage all stakeholders in preparing the information system process taking into consideration ICT technology possibilities (Cieplińska, 2019).

The regulations and norms governing inland navigation in Brazil are currently derived from regulations that originated from the maritime sector. However, many of these directives do not take into consideration the unique characteristics of the hydrographic basins found in Brazil. The regulations related to inland navigation in Brazil include the Constitution of the Federative Republic of Brazil of 1988, laws and decrees of the Presidency of the Republic specific to the waterway sector, norms of the Brazilian Navy, and resolutions of Antaq. There is a gap in the regulatory framework that has been identified, which allows for the simplification of the normative processes of inland navigation (Transporte C. N., Aspetos Gerais da Navegação Interior no Brasil, 2019).

Attending to the literature and the analysis of São Paulo reality, the following framework is suggested to give some guidelines on IWT implementation. This framework focuses on the identification of the main stakeholders and some problematics, the main challenges and also the problems to be addressed in order to benefits could be reached with it. (Figure 3).

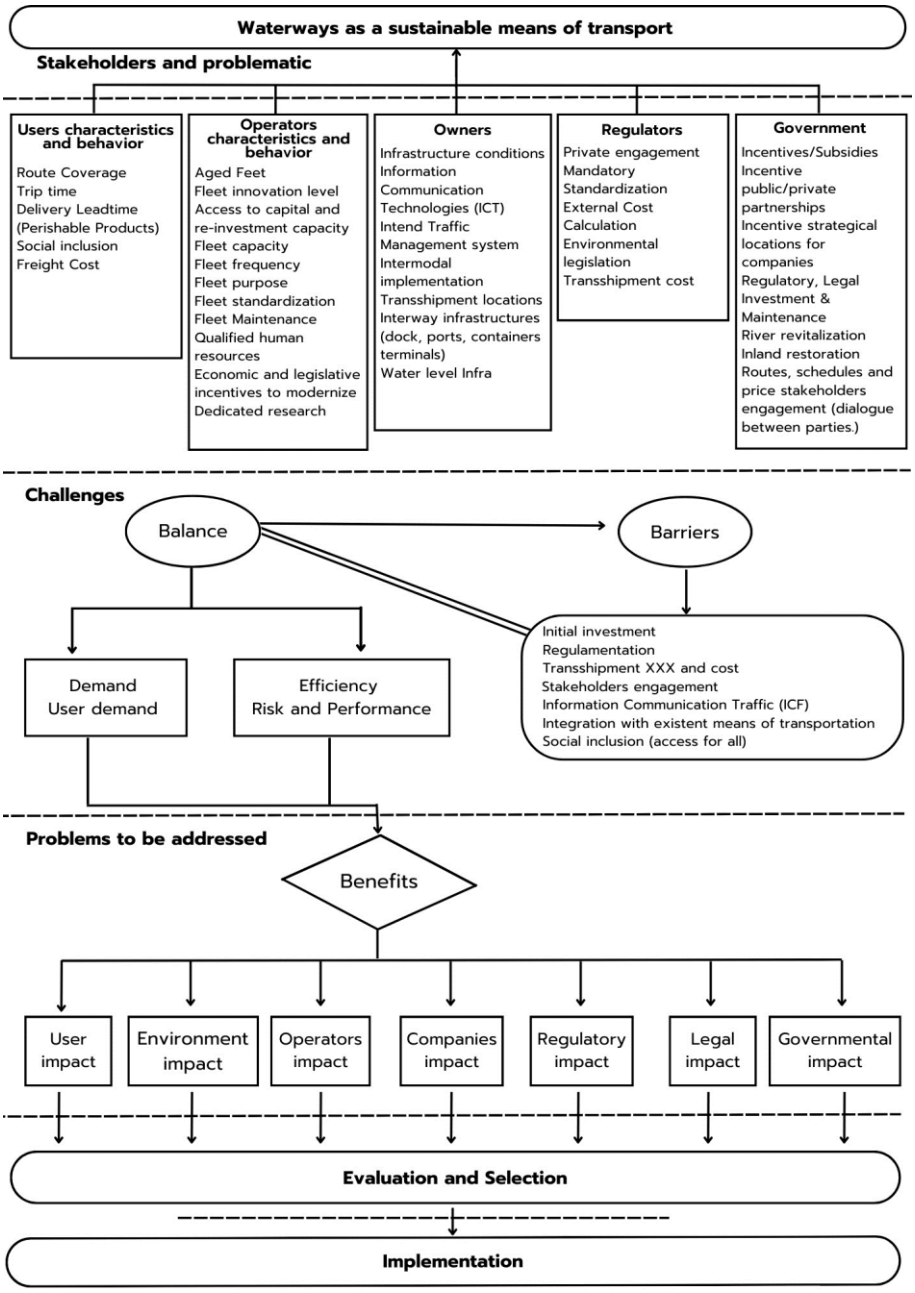

Figure 3. Framework proposal

5. Conclusion Discussion and conclusion

The main objective of the study was to conduct research to evaluate the main challenges for implementing inland waterway transportation in the urban circuit of São

Paulo. Firstly, related works, aiming to identify the main challenges and factors of success were identified. The analysis identified the main challenges to implementing a waterway, categorized into multidisciplinary factors, such as Technical, Environmental, Economical, Governance, Social, and Legal.

The study emphasized that the city's mobility projects should not be carried out independently, as they are part of an urban ecosystem with interdependent actions.

The implementation of sufficient transshipment locations along the canals and adequate space for loading and unloading on the city's river margins is crucial to allow for efficient loading and unloading assessments. The lack of this infrastructure will result in additional time and cost increases for various stakeholders.

There is a clear need for the development of intermodal transport networks to facilitate the efficient movement of goods and passengers. The study recommends integrating IWT with different modes of transportation, such as road, air, and rail, as well as encouraging the use of bicycle paths for urban mobility.

Service vessels can be used to maintain navigability conditions in urban rivers and may be used in heavy industry, construction materials, urban waste collection, and reverse logistics.

Floating distribution centers can be a solution to reduce the number of vehicles circulating in São Paulo by using smaller vessels such as electric or hybrid boats for distributing small parcels within the city center could be a viable solution. This approach could also facilitate navigation in regions with low water density and integrate with other means of transportation. Moreover, implementing last-mile delivery with emission-free vehicles such as electric bicycles or electric vehicles can promote sustainable transportation and access areas that are not accessible by trucks.

The integration of IWT in the intermodal supply chain can face several economic challenges. One major challenge is the need for investment in infrastructure, including locks and canals, which can be costly and limit adoption by some businesses. This challenge should become a priority because according to the OECD (2011) these types of infrastructures will become even more important for their national economies in the future. In addition, the initial cost of purchasing cargo bikes and associated equipment for last-mile delivery can also be high, discouraging adoption by some companies. The adoption of electric vessels may require significant capital investment and additional costs for operation and maintenance compared to traditional vessels, which can discourage some operators from investing in electrification.

Regulation and taxation can also pose economic challenges. A lack of clear regulatory frameworks can hinder investment in the sector, and policies related to fuel taxation and subsidies can impact cost competitiveness compared to other modes of transport.

It is also important to consider the long-term economic benefits of intermodal transport systems when making investment decisions, as they can lead to cost savings and improved efficiency in the long run. Cost savings and efficiency were identified a long time ago as important benefits of inland navigation (Janjevic and Ndiaye, 2014) as well as an important support to other transportation modes and services such as transport of palletized goods, transport of containerized goods, deliveries to local shops and restaurants, deliveries of parcels, transport of waste and recycled materials, and service trips.

Limitations

Besides the contributions of this ongoing research to the area, some limitations arise. One important challenge that should be considered in the proposed framework is climate change because of its influence on inland waterway transport through disturbances in waterway hydrology. According to Koetse and Rietveld (2009) and Jonkeren et al. (2011) climate change influences transportation costs since to allow fully loaded barges, the water level must be at the right level to allow maximum load of barges and thus reducing the transportation costs.

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