Enhancing Port Accessibility: Challenges, Measures, and Sustainability in Terminal Design

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Abstract. Port accessibility is a crucial factor in promoting sustainable development, as it directly impacts the three pillars of sustainability: economic growth, environmental quality, and social equity. Within the port context, accessibility plays a significant role in shaping operational performance, competitiveness, and the integration of the port with its surrounding environment. This study critically examines the main challenges and measures related to accessibility, delving into its distinct dimensions concerning both people and freight. For individuals, accessibility focuses on enabling citizens and tourists to easily and comfortably access the port and its associated urban or leisure activities. For freight, it emphasizes the necessity of an efficient multimodal transport network that facilitates the swift entry, handling, and departure of goods, with seamless connections to inland terminals.

The methodology includes an overview of the main challenges in understanding the role of accessibility in port terminals, the challenges and the definition of the criteria for accessibility in port terminals by the different stakeholders involved in the process. This approach provides a foundation for addressing accessibility-related issues and proposing measures that foster the development of competitive, integrated, and sustainable ports.

Keywords: Port Accessibility · Sustainable Development · Network analysis · Port Competition · Terminal Design

1 Introduction

The increasing attention in sustainable development has underlined the importance of accessibility as a valuable criterion for each of the three pillars of sustainability: economic growth, environmental quality and social equity. It is well known that the application of the concept of accessibility to a port has significant potential in determining and explaining the operational performance, competitiveness and economic performance of port (Wang and Cullinane, 2008), therefore accessibility is a core component of port development. Moreover, accessibility directly affects port-city relationships.

Port accessibility concerns:

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– people, as citizens and tourists should have the possibility to simply and comfortably access the port and the leisure or urban life related activities located into;
– freight, indeed a competitive port is a node of an efficient transport network that allow easy and rapid entrance-handle-departure of merchandise, so an adequate accessibility with road and rail have to be assured, as well as the connection with inland terminals.

Therefore, the accessibility is not limited to the physical connection between port and hinterland but includes the facilitation of the movement of goods and people, the elimination of architectural barriers, modal integration, and the availability of digital and information services. Thus, an analysis of accessibility should require information about the maritime/road/railway transport network, geographical constraints, costs and the distribution of potential origin/destination sites.

Especially for freight transport, the location problem is essential because freight cannot act like a person selecting one destination from a group of potential locations for one purpose (Michalk et al., 2011). Moreover, elements affecting accessibility for freight transport are quite different from those of public or private transport of people, as shown in Fig. 1.

mode / elements	car	public transport	bicycle/walk	freight
time	walking to parking place	hidden waiting time	travel time	loading
	in veichle travel time	travel time of access / egress mode	bicycle parking	transport documents
	congestion time	waiting time at station		transport time (diff. modes)
	finding a parking place	in veichle travel time		transhipment
	walking to destination	transfer time		waiting at ramp, unloading
costs	fixed costs	cost of tickets/ fares	fixed costs	driver costs
	fuel costs		maintenance costs	depreciation
	maintenance costs			fuel and maintenance
	parking costs			rail/road use pricing
	raod pricing costs			insurance
effort	level of dis(comfort)	level of dis(comfort)	level of dis(comfort)	quality of transport
	physical effort	physical effort	physical effort	supply chain / network
	reliability	reliability	social safety	administration
	stress	stress		energy consumption
	accident risk	accident risk		reliability
	information	social safety		accident and theft risks
	status	information		tracking and tracing
		status		value added services

Fig. 1. Differences between elements affecting accessibility for personal and freight transport (Source: Michalk et al., 2011).

Besides that, port accessibility also depends on port types; among classifications within literature (Lam and Iskounen, 2010; Notteboom, 2009; Park and Medda, 2010; Siviero, 2004) based on various criteria (e.g. hierarchy, generation) are relevant the functional definitions of hub port, gateway port and feeder ports.

However, the focus is often on the one hand on the quality of the maritime connections (linking the ports together; another approach has been defined by the PAI - Port Accessibility Index), which takes into account the characteristics of the port, and on the other hand on the internal accessibility of the port (Fancello et al., 2023).

An ideal situation for a port is to have a good accessibility both for people and for freight; generally, it should have a direct relationship with the city center thanks to high quality pedestrian and cycling paths and areas, with a reduced interference with vehicular

traffic, as well as good transit accessibility (Giuffrida et al., 2020). At the same time, the port should assure a high quality to commercial and operational activities that require adequate transport infrastructures for vehicular traffic.

In the European context, the Green Deal and the Sustainable and Smart Mobility Strategy place the maritime sector at the heart of the ecological and digital transition (European Commission, 2020). Strengthening port accessibility is thus part of a systemic vision that includes the decarbonization of transport, sustainable intermodality, the digitization of logistics services and the reduction of inequalities in access to infrastructure.

Therefore, it is crucial to ensure that maritime terminals are accessible, efficient and sustainable, in response to a growing global demand for inclusive mobility and environmentally friendly freight transport. Port accessibility needs to be considered in the infrastructural domain (e.g. intermodal connections, architectural barriers), in the logistical and operational domain (e.g. flow management, smart technologies) and in the environmental and social domain (e.g. impact on local communities, equality in the use of port space).

In the context of intensifying trade flows, for both people and goods, and increasing focus on sustainable development objectives, ports face complex challenges involving the design, operational management and environmental impact of terminal infrastructures.

Therefore, this research analyses the main critical issues of accessibility in order to promote a systemic and sustainable vision of port terminal design, aiming to combine economic efficiency, reduced environmental impact and social inclusion, in line with the Sustainable Development Goals (SDGs), specifically SDG 9 (Industry, Innovation and Infrastructure), SDG 11 (Sustainable Cities and Communities) and SDG 13 (Climate Action) supported by EU (European Commission, 2020).

A novel element of the research is an integrated and multidimensional approach, which simultaneously addresses passenger and freight accessibility within port terminals. Through the inclusion of stakeholder-defined and sustainability-related criteria, the study serves as a useful reference to support the planning and design of inclusive, resilient and future-oriented port infrastructure.

2 Methodology

Port accessibility is a crucial element not only to ensure the operational efficiency and competitiveness of a port, but also to foster a harmonious relationship with the city and local communities. While a well accessible port can stimulate international trade and the flow of goods, a port design that takes into account urban integration and environmental sustainability can transform an industrial center into a dynamic and positive hub for the entire surrounding area. The challenges related to improving the accessibility of ports are multiple and interconnected.

Part of the methodology was implemented as part of the Design of Maritime Sustainable Terminals (DEMASTER) project, during which groups of potential stakeholders were identified to better define and tune the strategic objectives for the design of port terminals. Furthermore, different ports, organized into a large cluster focused on the Adriatic-Ionian area (Fig. 2), were selected as case studies in order to validate the design methodology.



Fig. 2. Case studies of DEMASTER project (Source: Authors' elaboration).

In order to identify the main challenges, measures and considerations for sustainability in the design of the terminals, a qualitative research approach was chosen, centered on the use of thematic focus groups in some ports of the cluster. This method made it possible to gather in-depth insights and different perspectives from a variety of port-related stakeholders. Figure 3 shows the different stages of the implemented methodology.

A series of focus group discussions were organized, each addressing specific topics such as accessibility, environmental impact, operational efficiency and user involvement. The thematic approach allowed participants to engage in focused dialog and the research team to gather detailed qualitative data on the practical and strategic dimensions of terminal design.

Participants were selected based on their roles and importance within the port ecosystem to ensure a heterogeneous mix of perspectives. The selection included:

- Port authorities and terminal operators
- Shipping and logistics companies (including ship owners and cargo operators)
- Trade and professional associations
- Urban planners and environmental consultants
- Representatives of civil society, including citizens' groups.

This diversification of profiles helped to ensure that both institutional priorities and social concerns were equally represented, allowing for a holistic understanding of terminal design challenges and potential solutions.

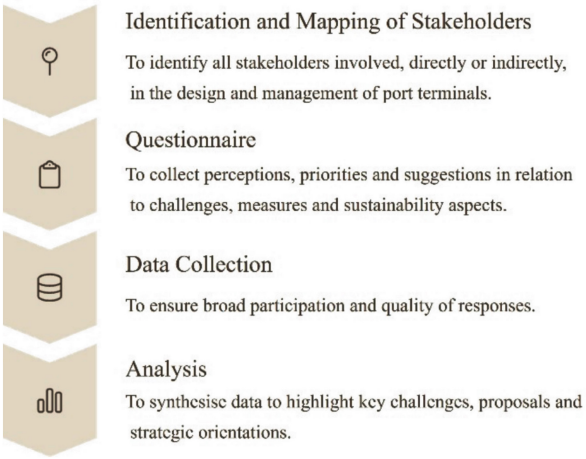

Fig. 3. Stakeholder Engagement Process (Source: Authors' elaboration).

3 Results and Discussions

The focus group sessions were semi-structured and led by facilitators familiar with port planning and logistics. Where appropriate, findings from the focus groups were cross-referenced with findings from secondary data sources such as policy reports, academic literature and regulatory guidelines to validate and enrich the qualitative analysis.

The results are divided into three tables dealing with the role of accessibility in port terminals (Table 1), the challenges for accessibility in port terminals (Table 2) and the criteria for accessibility in port terminals (Table 3).

Each group of stakeholders brings a unique perspective. For maritime and logistics stakeholders, the focus is on streamlining operations, i.e. shortening waiting times for ships, improving multimodal connections and reducing congestion. But achieving these goals often requires extensive infrastructure upgrades and the integration of new digital tools. This is difficult when many different players and systems have to work in sync.

For institutional and public entities, the challenges are often related to administration—aligning strategies, securing long-term funding and managing complex regulations. Port projects are closely linked to urban development, environmental goals and sometimes even geopolitics. This can lead to slow, fragmented decision-making and delays in important investments.

On the social and end-user side, the conversation is more personal. Accessibility is not just about infrastructure, but also about equity, safety and dignity. When ports serve both cargo and people, it's a constant balancing act to keep things efficient and make them welcoming and safe, especially for those who have difficulty with access, such as older travelers, people with disabilities or visitors who are unfamiliar with the area.

Improving port accessibility requires more than just building new infrastructure—it requires a coordinated effort that considers efficiency, connectivity and inclusivity (Fig. 4).

Table 1. Results of Role of Accessibility in port terminals (Source: Authors' elaboration).

Stakeholder category	Results
Maritime Stakeholders	Terminal accessibility improves loading and unloading times for goods and embarking and disembarking times for people by reducing waiting times and costs.
Operational/Logistics Stakeholders	Multimodal accessibility is crucial for the sorting of goods; bottlenecks cause delays and high costs; port accessibility on both sea and land sides optimizes loading and unloading times and improves competitiveness; smooth connections with hinterland and freight hub are crucial.
Institutional/Public Stakeholders	Accessibility is key to attractiveness and efficient logistics; port accessibility affects local economic and employment development.
Social/End-User Stakeholders	Accessibility with public transport and pedestrian infrastructures is essential for passenger terminals, especially for the most vulnerable groups; well-accessible ferry and cruise terminals are crucial for enhancing the travel experience.

Table 2. Results of Accessibility Challenges in Port Terminals (Source: Authors' elaboration).

Stakeholder category	Results
Maritime Stakeholders	Terminal congestion; limited access slots; insufficient infrastructure for larger vessels.
Operational/Logistics Stakeholders	Inadequate space; inefficient flows of incoming and outgoing goods; delays in access; long waiting times at gates; inadequate road connections; lack of traffic management systems; unpredictable flow times of goods; difficulties in tracking shipments between nodes; bottlenecks in rail and road interconnections; insufficient integration with logistics hubs.
Institutional/Public Stakeholders	Obsolete infrastructure; complex approval processes for new access projects. Urban traffic congestion; environmental impact; balancing port growth with city needs.
Social/End-User Stakeholders	Lack of public transport links; architectural barriers in passenger terminals; inadequate signage; poor accessibility without private transportation.

For the maritime stakeholders ports should focus on improving and modernizing their infrastructure. This includes the expansion of berths, the deepening of waterways

Table 3. Results of Accessibility Criteria in Port Terminals (Source: Authors' elaboration).

Stakeholder category	Results
Maritime Stakeholders	Adequate quay and terminal access for large vessels; Congestion-free berthing and turnaround zones; Availability of shore-side electricity (cold ironing); Digital coordination with land transport schedules.
Operational/Logistics Stakeholders	Smart gate systems and buffer zones for trucks; Scalable terminal layouts for cargo peaks; Charging infrastructure for electric trucks and handling equipment; Seamless cargo flow (sea-rail-road); IoT tracking and warehouse connectivity; Digitalization of cargo and equipment process, and gate status.
Institutional/Public Stakeholders	Electrification of quays (cold ironing) to reduce vessel emissions at berth; Integrated multimodal access (road, rail, sea, public transport); Environmental sustainability standards; Efficient customs zones and traffic flows; Port Community Systems (PCS) for integrated data sharing among actors - Digital customs clearance systems and pre-arrival notifications; compatibility with urban planning goals.
Social/End-User Stakeholders	Barrier-free passenger pathways (elevators, ramps, signage); - Easy public transport access; Centralized services (ticketing, waiting areas, info points); Integration with electric mobility (e-bus, EV charging stations); Passenger information systems (real-time schedules, notifications).

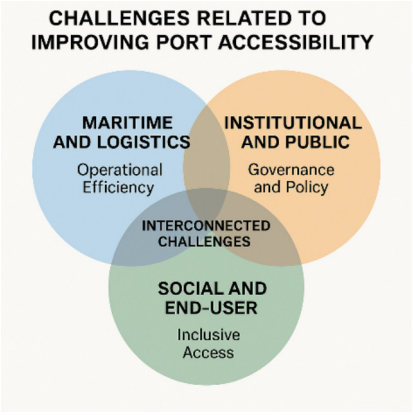

Fig. 4. Interconnected challenges between stakeholders (Source: Authors' elaboration).

for larger vessels and the introduction of intelligent planning systems that help to reduce congestion. Collaboration with private partners can also help accelerate infrastructure modernization and share financial responsibility.

Improving the flow of goods and connectivity is crucial for logistics and operational stakeholders. Expanding road and rail links to the port, especially seamless connectivity to inland freight hubs, will help reduce delays. The introduction of intelligent traffic management systems at the port gates can streamline truck movements and reduce waiting times. Digitizing shipment tracking across the supply chain will improve visibility and coordination. In addition, the development of nearby logistics parks or dry ports can help reduce congestion in the port's core area.

There is a clear need for institutional and public stakeholders to simplify the regulatory and approval processes for new access projects. Faster and more transparent planning can help overcome delays and ensure timely implementation. Urban and port development should be closely coordinated, especially in the border areas between city and port, to avoid conflicts and promote mutual benefits. Environmental concerns need to be addressed proactively, with clear strategies to reduce noise, air pollution and traffic. It is also important to involve and inform the public throughout the development process to build trust and support.

From a social and end-user stakeholder perspective, ports need to become more inclusive and user-friendly. Improving access to passenger terminals by public transport is crucial, especially for people who do not have access to private vehicles. Removing physical and architectural barriers will make it easier for all users, including people with disabilities, to navigate the terminals. Improved signage, available in multiple languages, and intuitive wayfinding systems will also help to improve the user experience. Ports should offer special services and spaces that meet the needs of vulnerable travelers, such as the elderly or people with reduced mobility.

To focus these efforts, it is recommended that ports develop a comprehensive port accessibility plan that includes infrastructure, logistics, technology and inclusive design. Regular stakeholder engagement should be encouraged through roundtables and consultation processes to ensure that decisions take into account the needs of all users. Pilot projects and innovation initiatives can serve as testing grounds for new ideas before they are implemented on a broader scale. Finally, ports should actively seek funding opportunities from regional, national or EU programs to support strategic improvements, especially those with long-term social and environmental benefits.

To improve port accessibility, we need to meet the real needs of the people who use, manage and depend on ports every day. In Table 3 are the answers for each affected group.

For maritime stakeholders ports need to be ready for modern ships—both in terms of size and technology. This means expanding berths and upgrading terminals so that larger ships can dock without delay. It is equally important to reduce congestion at the berths so that ships can enter and leave more smoothly. The installation of shore power (cold ironing) allows ships to turn off their engines while in port, reducing emissions and noise. For all this to run efficiently, ports should use digital tools to stay in sync with truck and train schedules so that everything comes together in real time.

For operational and logistics stakeholders the focus is on speed, efficiency and reliability. Introducing smart gate systems and creating buffer zones for trucks can reduce long queues and improve flow at peak times. Terminals should be flexibly designed to handle peak loads without causing chaos. As part of the shift to greener logistics, it is also important to install charging stations for electric trucks and equipment. On the technical side, the integration of real-time tracking systems and digital warehouse connections will keep goods moving and make the whole process more transparent and predictable.

Public authorities play an important role in shaping the accessibility and sustainability of ports. Investments in shore power systems support cleaner port operations and are in line with environmental goals. Smooth customs procedures are crucial and can be improved by digital pre-arrival systems that reduce waiting times. Data exchange between all parties via a Port Community System (PCS) also improves coordination. And importantly, all of this needs to be aligned with urban planning so that ports grow in harmony with the surrounding cities.

For social and end-user stakeholders the port areas—especially passenger terminals—should be welcoming and accessible to everyone. This means creating barrier-free pathways with ramps, elevators and clear signage for people with reduced mobility. It also means making it easy to get to and from the port by public transport, not just by car. Within the terminal, centralized services such as ticket counters, information points and comfortable waiting areas should be available and easy to find. And with real-time information systems, travelers can find out about timetables, changes and available services.

By bringing together these improvements—better infrastructure, cleaner technologies, smarter systems and more thoughtful design—we can create ports that are not only efficient and competitive, but also welcoming, sustainable and future-proof. This requires collaboration, investment and a shared commitment to building ports that truly work for everyone.

4 Conclusion

The design and development of port terminals are no longer just a question of infrastructure and logistics—they are complex, multi-dimensional challenges that must meet economic, environmental, social and technological requirements. This paper highlights the link between port accessibility, sustainability and stakeholder involvement and emphasizes that sustainable terminals require a holistic, collaborative approach.

In thematic focus groups, various stakeholders—including port authorities, logistics companies, trade associations, urban planners and citizen groups—identified key barriers, such as infrastructure constraints, congestion, policy fragmentation and gaps in inclusive design. These findings underscore the need for a coordinated approach that balances efficiency and inclusiveness, operational speed and long-term sustainability.

To address these challenges, the paper makes a number of practical and forward-looking recommendations, from modernizing port infrastructure and digitizing logistics flows to improving public transport links and integrating clean energy solutions. Transportation planning is no longer conceivable without the use of modern technologies, smart solutions and intelligent services (Stojaković and Twrdy, 2024). The introduction

of smart port technologies—such as AI, IoT and real-time dashboards for accessibility—is proving to be a crucial factor that can transform terminals into dynamic, adaptable systems.

The integration of Artificial Intelligence (AI) and Internet of Things (IoT) technologies into port operations offers significant potential to improve efficiency and responsiveness. These technologies can be used to predict congestion patterns, optimize traffic and cargo routes in real time and support proactive decision-making. By dynamically coordinating resources, smart port systems contribute to smoother operations, shorter waiting times and improved throughput, supporting both operational efficiency and environmental goals (Acciaro et al., 2014).

Ultimately, the success of terminal design lies in its ability to serve all users efficiently, equitably and sustainably. Achieving this goal requires more than just investment in hardware. It requires ongoing stakeholder collaboration, a clear policy framework and a commitment to innovation that puts people and the environment at the heart of port development.

To address the environmental impact of port transportation, ports should explore solutions for low-emission last-mile connectivity, such as the integration of bike-sharing systems, electric shuttle services and other forms of green mobility. These measures not only help to reduce congestion and emissions in urban areas adjacent to the port, but also improve accessibility for port workers and passengers, which fits into broader strategies for sustainable urban transport (OECD, 2014).

The development of publicly accessible digital dashboards that display real-time accessibility data is a forward-looking approach to stakeholder engagement and operational transparency. These platforms can provide live updates on access conditions, traffic flows and modal connectivity, helping logistics providers, authorities and end users to make informed decisions. Such tools also support joint planning and improve accountability by giving stakeholders better insight into the performance and accessibility of port systems (European Commission, 2020).

The research was conducted on a selection of case studies analysed within the DEMASTER project. Consequently, the results obtained reflect the limitations related to the number and specificity of the contexts examined. However, this analysis offers a solid basis for future in-depth analysis and expansion, which could include a larger number of cases, involving other countries in the identified geographical cluster (as shown in Fig. 4). The results obtained represent a useful contribution to improving planning and design processes in the sector, orienting them towards principles of environmental sustainability, social equity and climate crisis mitigation.

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