

CASE STUDY IDENTIFICATION SHEET

This document has been developed as part of the activities under Task 3.2 of the “GREENPORT Alliances” project, for which MAR.TE. S.c.ar.l. serves as the responsible entity. Task 3.2 focuses on identifying and analyzing case studies that exemplify best practices for behavioral change among operators aimed at reducing the environmental impact of port operations.

The primary objective of this activity is to collect, document, and analyze concrete examples of technological, managerial, or behavioral innovation that have proven effective in contributing to the environmental, economic, and social sustainability of the port services sector. Through a structured selection and evaluation process, the document highlights the specific features of each case study and assesses their performance against key environmental and economic impact indicators.

The information gathered will be integrated into the overall framework of the GREENPORT Alliances project to promote the dissemination of sustainable solutions and the development of curricula for: a. higher education students (future personnel); b. current professionals (professional training); c. educators (train-the-trainer courses).

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1. GENERAL INFORMATION

A. **Case study title**

AR Pilot Navigation Aid: enhancing efficiency and safety at the port of Livorno.

B. **Green practice implemented**

The two practices most relevant to the case study of the AR Pilot Navigation Aid system are:

a. **Practice 4: Collaboration among stakeholders for real-time data sharing**

- The success of the AR system relies on collaboration among various stakeholders (pilots, port operators, technology developers) and the integration of platforms such as MONI.C.A. and the Tuscan Port Community System (TPCS). This collaboration facilitates real-time sharing of key data, improving communication and coordination among all parties involved, reducing risks, and increasing overall efficiency.

b. **Practice 14: Real-time navigation route optimization**

- This practice is central to the case study, as the AR system enables port pilots to access real-time critical data regarding route, speed, position, and vessel characteristics. Real-time route optimization not only enhances operational efficiency but also reduces fuel consumption and greenhouse gas emissions, directly contributing to environmental sustainability goals.

These two practices represent the fundamental pillars of the case study, as they reflect the added value generated by integrating advanced technologies with a collaborative approach to port operations management.

C. **Specific goals**

- Support port pilots in daily operations, promoting safety, ergonomics and efficiency.
- Enhance navigation accuracy and optimize resource use through AR technology.
- Facilitate seamless integration of port systems like MONI.C.A. and TPCS.

D. **Direct impact of the practice**

- Improved communication between pilots and ground crews.
- Improved safety and decision-making for port pilots.
- Enhanced operational efficiency and reduced resource wastage.

E. **Place of implementation**

Port of Livorno (Northern Tyrrhenian Sea Port System Authority), Italy.



Figure 1 - Location of the Port of Livorno

The Port of Livorno (Figure 1) is situated on the western coast of Italy, along the Ligurian Sea, which is part of the larger Tyrrhenian Sea. It is located in the Tuscany region, near major Italian cities such as Pisa and Florence. Geographically, Livorno serves as a strategic maritime gateway for both commercial and passenger traffic in the Mediterranean.

F. Start and end date or duration of the pilot project

October 2021 (pilot testing) – Optimization (2022)

2. CONTEXT AND DESCRIPTION

A. Description of the practice

The **AR Pilot Navigation Aid** system was implemented at the Port of Livorno as part of the European “PortForward¹” project to enhance navigation operations in port waters. This innovation not only introduces advanced technologies, such as smart glasses equipped with augmented reality, but also fosters a crucial cultural shift among port operators.

By enabling real-time visualization of essential information – such as route, speed, and vessel position – maritime pilots and tug operators are encouraged to adopt more informed and sustainable practices in their daily activities. The combination of technology and behavioural change reduces reliance solely on individual experience, promoting a data-driven decision-making culture based on accurate and up-to-date information.

The adoption of this system represents not just a technological advancement, but an opportunity to promote a collective approach focused on environmental sustainability. The optimization of routes and the reduction of human errors – facilitated by augmented reality – directly impact the reduction of greenhouse gas emissions and fuel consumption. Additionally, the system fosters smoother and more collaborative communication among stakeholders, creating the conditions for more efficient and responsible port operations. This transformation is not just technical but behavioural, requiring operators to embrace a new mindset that values digitalization and sustainability as key elements of their work. Targeted training and continuous support have proven essential in overcoming initial resistance, demonstrating that adopting new tools can lead to tangible benefits for both the environment and port competitiveness. In this context, the Port of Livorno stands as a pioneering model, showcasing how the synergy between technology and cultural change can drive the maritime sector toward a greener and more efficient future.

B. Driving factor behind the adoption of the green practice

The adoption of the AR Pilot Navigation Aid system at the Port of Livorno was primarily driven by the need to enhance port operation safety, optimize the use of available resources, and minimize human error. This case study is part of a broader port digitalization process, considered essential to ensuring competitiveness, economic sustainability, and compliance with environmental regulations.

The introduction of this technology addresses the growing demand for **innovative solutions in the maritime sector**, necessary to tackle the challenges of modernization and ecological transition. The integration of RealWear HMT-1 smart glasses with existing digital platforms **has optimized navigation maneuvers**, improved coordination among stakeholders, and reduced both fuel consumption and emissions.

¹ The **PortForward** project is an initiative funded by the European Union under the Horizon 2020 program, aimed at making ports smarter, more sustainable, and more interconnected. The main objective is to improve the operational efficiency and environmental sustainability of port infrastructures through the use of advanced technologies, such as the Internet of Things (IoT), Artificial Intelligence (AI), Big Data, and Augmented Reality

Beyond operational improvements, the case study aims to achieve **a long-term strategic impact** by fostering a cultural shift among pilots and port operators. The adoption of digital tools has encouraged a more structured, data-driven approach, reducing exclusive reliance on individual experience and promoting **a more efficient and sustainable management of port operations**.

c. Stakeholders involved

A list of stakeholders actively involved in the case study:

- **Northern Tyrrhenian Sea Port Authority** (provider of technical requirements and basic infrastructure).
- **Port pilots of Livorno** (primary users of the system).
- The company **TeamViewer** (developer of the AR solution and technical support provider).
- **Port operators** (involved in the integration with existing systems such as MONI.C.A.).

3. IMPLEMENTATION

A. Description of the adopted practice

The project included the following four steps:

1. Operational requirements analysis: Identifying the specific needs of pilots.
2. Technological integration: Using RealWear HMT-1 “smart glasses” and connecting them to MONI.C.A². and TPCS systems via REST APIs.
3. Workflow development: Creating digitized procedures for navigation assistance.
4. Testing and validation: Pilot implementation onboard the Eco Valencia vessel with field evaluations.

The AR Pilot Navigation Aid project was structured into four key phases, each designed to ensure effective implementation and meet the specific needs of pilots and tug operators at the Port of Livorno.

Phase 1: Operational Requirements Analysis

The first phase involved an in-depth analysis of operational requirements, aiming to understand the practical needs of operators during daily activities. This process included studying the specific challenges of port navigation, such as managing restricted water spaces, complex manoeuvres, and the need for accurate, real-time data. The primary objective of this phase was to precisely define the tools and essential functionalities required to enhance the safety and efficiency of pilotage operations.

Phase 2: Technological Integration

The second phase focused on technological integration, a crucial aspect for the project’s success. RealWear HMT-1 smart glasses – known for their durability and ability to function in challenging weather conditions – were selected for deployment in port operations. These devices were connected to existing digital platforms, such as the MONI.C.A. monitoring system and the Tuscan Port Community System (TPCS), through a REST API system. This integration allowed pilots to seamlessly access critical data – including route, speed, vessel characteristics, and position – through an intuitive real-time interface.

Phase 3: Development of Digital Workflows

The third phase focused on developing digital workflows, designed to provide pilots with clear and structured operational procedures. These workflows transformed traditional procedures into digital processes, improving accuracy and consistency in operations. Using *Frontline Creator by TeamViewer* – the developer of the AR solution and technical support provider – digital workflows were created

² **MONI.C.A.** is the monitoring and control platform of the Northern Tyrrhenian Sea Port System Authority. The platform acquires and integrates heterogeneous data from multiple information sources, whether applications or distributed sensors. MONI.C.A.'s services are organized into specific functional areas and are intended for a wide range of users, both public (e.g., port authority, harbour master’s office, customs, financial police, etc.) and private (e.g., port operators, logistics providers, trucking companies, passengers).

to include steps such as: a. automatic GPS-based position detection; b. ship selection based on location; c. access to detailed vessel data, including characteristics and trajectories.

Phase 4: Field Testing and Validation

The final phase involved extensive field testing and validation, essential for assessing the system's effectiveness in real-world conditions. This phase was conducted aboard the *"Eco Valencia"*, an operational vessel used to simulate real navigation scenarios at the Port of Livorno. During testing, pilots used the smart glasses to evaluate the system's functionalities and provide detailed feedback.

Field evaluations helped identify potential areas for improvement, ensuring that the system fully met the practical needs of pilots and the expectations of stakeholders. This iterative process contributed to optimizing the system, ensuring seamless integration between technology, operations, and safety.

B. Technologies used (if applicable)

- RealWear HMT-1 "smart glasses".
- TeamViewer Frontline Command Center for user and workflow management.
- REST APIs for integration with MONI.C.A. and TPCS.
- Wi-Fi and GPS connection for real-time data.

The AR Pilot Navigation Aid system relies on a combination of advanced technologies, specifically designed to assist pilots and tug operators in the complex navigation operations within port waters. At the core of this innovative solution are the **"RealWear HMT-1"** smart glasses, highly robust and resistant devices, ideal for use in challenging and dynamic environments such as ports. The RealWear HMT-1 (Figure 2) is an industrial-grade wearable device, designed for workers who require hands-free access to digital information. Equipped with an adjustable monocular display, the headset creates the effect of a seven-inch screen positioned at a virtual distance, allowing users to view data, access technical manuals, or participate in remote assistance sessions without taking their eyes off their work. Navigation is performed exclusively via voice commands, ensuring a seamless interaction even in noisy environments, thanks to an advanced voice recognition system.

Designed to withstand extreme conditions, the device is waterproof, dustproof, and capable of enduring shocks and drops, meeting IP66³ and MIL-STD-810G⁴ certification standards. Its hot-swappable battery allows for extended use without the need to power down the device, making it ideal for intensive work shifts. Thanks to its compatibility with platforms such as TeamViewer, Microsoft Teams, and Zoom, the RealWear HMT-1 is widely used for remote assistance, enabling operators to receive real-time support from experts who can view what the user sees and provide precise guidance. This technology not only enhances operational efficiency but also significantly

³ The **IP66** certification falls under the **IEC 60529** standard and indicates that a device is completely protected against dust and resistant to powerful water jets from any direction, although it is not designed for prolonged submersion.

⁴ The **MIL-STD-810G** certification is a U.S. military standard issued by the United States Department of Defense that tests a device's resistance to extreme environmental conditions, including shocks, vibrations, extreme temperatures, altitude, exposure to dust, sand, and humidity. This standard is commonly adopted for devices intended for industrial, military, or outdoor use, such as rugged laptops, smartphones, and equipment designed for harsh environments.

improves workplace safety by reducing the need for on-site interventions and optimizing maintenance and training processes.

These smart glasses are equipped with augmented reality (AR) capabilities, allowing pilots to access real-time critical data while keeping their hands free.

This feature not only enhances operational efficiency and productivity but also improves safety levels by reducing the risk of distractions and enabling operators to fully focus on manoeuvring.



Figure 2 – RealWear HMT-1 Smart Glasses

The system is managed through the “*TeamViewer Frontline Command Center*”, a centralized platform that plays a crucial role in configuring and administering operations. This tool allows for the creation, customization, and monitoring of digitized workflows, specifically designed to meet the unique needs of pilots. The platform also enables efficient user management, assigning specific roles and tasks, while tracking system performance data to provide a comprehensive overview of ongoing operations. This approach ensures a high level of control and facilitates the customization of processes, making the system flexible and adaptable to various operational requirements.

A key factor in the project’s success is its integration capability with the port’s existing digital platforms, such as the MONI.C.A. monitoring system and TPCS. This integration is achieved through the use of REST APIs, which act as an interface between port system data and the smart glasses. Thanks to this connection, pilots can access real-time, detailed information about vessels, including exact position, route, speed, and technical specifications. This continuous real-time data flow is essential for supporting fast and informed decision-making during navigation operations.

The system’s functionality also depends on a stable Wi-Fi connection, which can be ensured through a mobile hotspot. Additionally, precise GPS reception is a critical requirement, allowing the smart glasses to accurately detect geographic location and provide relevant contextual information in real time. The combination of these advanced technologies, along with the integration of port data, provides pilots with unprecedented support for maneuvering operations, significantly enhancing both efficiency and safety.

c. Competencies required

- Technical skills: Managing AR devices and interpreting GPS and sensor data.
- Operational training: Educating pilots on using “smart glasses” and interacting with data.
- Environmental awareness: Understanding the sustainability benefits of operations.

The implementation of the AR Pilot Navigation Aid system at the Port of Livorno required an integrated set of technical, operational, and environmental awareness skills to ensure maximum success and full adoption by pilots and tugboats. From a technical perspective, it was essential for operators to become familiar with managing augmented reality devices, such as smart glasses, and interpreting data from sensors and GPS. These skills enabled them to make the most of the system’s advanced features, such as real-time visualization of navigation-related information and ship characteristics.

At the same time, an operational training program was crucial to ensure that pilots were adequately prepared to use the system effectively. This training included hands-on education on the use of smart glasses and interaction with digital data integrated into the MONI.C.A. and TPCS platforms. The goal was to ensure that pilots could navigate with greater precision and safety, leveraging the system’s capabilities to enhance the efficiency of port operations.

Another key aspect was environmental awareness, which was an essential component of this project. Pilots were educated on the sustainability benefits associated with adopting advanced digital technologies. This included understanding how optimizing operations through the AR system could help reduce the port’s overall environmental impact, improve energy efficiency, and minimize emissions. The integration of technical, operational, and environmental skills made this solution not only a technological advancement but also a significant step toward more sustainable and innovative port management.

4. COLLECTED DATA

Secondary source analysis did not provide data on the *Key Performance Indicators* (KPIs) that should have monitored the ex-post effects of the devices supporting pilots and tugboats. The absence of such data prevents a quantitative assessment of the effectiveness of the adopted technologies, limiting the analysis to qualitative aspects or preliminary considerations. A systematic collection of KPIs would have been essential to measure the concrete impact of the implemented solutions in terms of operational efficiency, safety, and response times. However, the following section presents some reflections on the critical issues that existed before the introduction of the devices and the tangible benefits resulting from their use.

A. Before implementation

- High margin of human error during navigation.
- Limited communication between pilots and ground crews.
- Lack of real-time visibility on ship characteristics.

Before the adoption of the AR Pilot Navigation Aid system, piloting and towing operations at the Port of Livorno faced several critical issues that affected both operational efficiency and navigation safety. Reliance on manual procedures and verbal communication between pilots and shore teams often led to delays and misunderstandings, increasing the risk of maneuvering errors. The lack of real-time access to critical ship data - such as dimensions, speed, and maneuverability - forced pilots to rely primarily on experience and rough estimates, making operations less predictable and potentially more hazardous.

Another significant limitation was the lack of seamless data integration among various port stakeholders. Information on traffic, weather conditions, and berth availability was scattered across different systems, requiring manual retrieval and processing that slowed down operations and extended response times in critical situations. Additionally, the absence of augmented reality technology required pilots to constantly shift their focus between the surrounding environment and onboard instruments, reducing situational awareness and increasing cognitive load. Environmental aspects were also not adequately managed under the traditional system. Inefficient route planning and excessive fuel consumption were common issues. Without real-time optimization tools, manoeuvring delays and suboptimal routes contributed to higher fuel consumption and increased emissions, negatively impacting the port's sustainability goals.

These challenges underscored the urgent need for a technological transformation to enhance piloting operations, minimize human error, and introduce a data-driven approach to optimize navigation accuracy, efficiency, and environmental performance

B. After implementation:

- Immediate access to ship data via “smart glasses”.

- Improved communication through remote support functionalities.
- Reduced response times in critical situations.

After the implementation of the AR Pilot Navigation Aid system, piloting and towing operations at the Port of Livorno saw significant improvements in efficiency, safety, and sustainability. One of the most notable changes was real-time access to critical navigation data through the use of augmented reality (AR) smart glasses. Pilots were able to instantly view essential information about ship dimensions, speed, manoeuvrability, and position, reducing reliance on rough estimates and enhancing decision-making accuracy.

The integration with the MONI.C.A. platform and the Tuscan Port Community System (TPCS) enabled smooth communication and real-time data exchange between pilots, tugboat crews, and port operators. This improved situational awareness, reduced response times, and minimized the risk of errors during manoeuvres. Additionally, the hands-free operation enabled by the smart glasses optimized ergonomics and reduced distractions, allowing pilots to fully focus on navigation while receiving real-time guidance.

Another key benefit was the optimization of navigation routes, leading to reduced fuel consumption and lower greenhouse gas emissions. Thanks to real-time data analysis, pilots were able to make more informed and sustainable decisions, contributing to the port's environmental goals. The increased efficiency also allowed for shorter berthing times, lowering operational costs and enhancing the reliability of port services. The adoption of AR technology also transformed the training and knowledge-sharing processes among pilots. The ability to record and analyze real navigation scenarios facilitated practical learning, enabling new pilots to familiarize themselves more quickly with port operations. This contributed to greater standardization of decision-making processes and a more structured approach to risk management.

The success of the AR Pilot Navigation Aid system's implementation demonstrated how digital innovation can transform port operations, making them more efficient, safer, and sustainable. The experiences gained in Livorno represent a scalable model that can be replicated in other ports seeking to improve navigation efficiency and environmental performance through the use of technology.

5. ECONOMIC AND ENVIRONMENTAL ANALYSIS (*IF THE INFORMATION IS ACCESSIBLE*)

A. Initial investment required

- AR devices and hardware: € 25.000.
- Software development and integration: € 40.000.
- Training: € 15.000.

The implementation of the AR Pilot Navigation Aid system at the Port of Livorno involved detailed planning of costs and resources necessary to ensure the success of the project. The main investments focused on three key areas: 1. AR devices and hardware; 2. software development and technological integration; 3. staff training. Regarding equipment, the purchase of smart glasses and other essential hardware devices incurred a total cost of approximately € 25.000.

Another crucial element of the project was the development and integration of software, which required a total investment of around € 40.000. This phase included the creation of digitized workflows, the implementation of REST API interfaces for connection with the MONI.C.A. and TPCS platforms, and the integration of real-time data to enhance the system's operational effectiveness. The developed software enabled pilots to access critical information, such as course, speed, and ship characteristics, directly on the AR devices.

Finally, to ensure optimal use of the technology, a dedicated training program was conducted for the involved staff. This program had a cost of approximately € 15.000 and focused on: a. training pilots on the use of smart glasses; b. managing digital data; c. interacting with the integrated platforms. Overall, the total investment represented a significant but necessary commitment to improving the safety, efficiency, and sustainability of port operations.

B. Key savings or economic impact

- Improved operational efficiency due to reduced maneuvering times.
- Enhanced safety, reducing risks of damage to ships and port infrastructure.

The adoption of innovative technologies, such as augmented reality (AR) tools for pilot navigation, represents a paradigm shift in port operations, offering solutions that combine efficiency, sustainability, and safety.

These systems, as demonstrated by tests at the Port of Livorno, allow for significant optimization of maneuvers, thanks to the ability to reduce operational times and, consequently, the costs associated with fuel consumption and resource management. The ability to monitor and analyze real-time data improves the accuracy of operations and greatly reduces human errors. Furthermore, the integration of remote assistance based on video and audio enables immediate support in critical situations, increasing safety for both ships and port infrastructure. This approach not only enhances decision-making efficiency but also promotes optimal resource management and contributes to achieving long-term sustainability goals, as outlined by European Union standards. The economic impacts extend beyond direct savings on operational costs to include indirect and far-reaching benefits. For example, improvements in safety reduce the need for extraordinary interventions to repair damaged infrastructure, while optimizing operations enhances the overall productivity of the port.

Additionally, the increased satisfaction of operators and customers creates a competitive advantage that can attract new investments and business opportunities.

Social and organizational benefits are also evident. Pilots and tugboats, the primary users of these technologies, benefit from tools that simplify their work and reduce the stress associated with complex operations. The introduction of AR solutions also fosters the creation of a safer and more modern work environment, improving workers' well-being and supporting the transition to more digitalized and resilient ports.

Finally, this technological transformation offers tangible benefits for all parties involved: the port authority gains more accurate control over operations and more efficient infrastructure management, while logistics operators can rely on faster and more reliable transit times. Long-term impacts include increased overall efficiency of the port system, greater resilience to future challenges, and a significant contribution to reducing carbon emissions, aligning the sector with global sustainability goals

c. Contribution to environmental goals

- Optimized operations to reduce consumption and emissions.
- Promotion of sustainable digital technologies.

Optimized port operations not only reduce fuel consumption and greenhouse gas emissions but also encourage a cultural shift among operators, which is essential for improving overall efficiency and promoting environmental sustainability. The introduction of innovative tools such as augmented reality (AR) systems and smart glasses transforms daily workflows, improving maneuver precision and real-time decision-making ability. This not only offers operational advantages but also fosters greater awareness of environmental impact and more responsible resource management.

The adoption of these innovative technologies directly contributes to achieving key environmental goals:

- **Optimization of operations to reduce consumption and emissions:** The digitization of processes allows for minimizing energy waste and optimizing routes, thereby reducing fuel consumption and greenhouse gas emissions associated with port operations.
- **Promotion of sustainable digital technologies:** The integration of advanced platforms like MONI.C.A. and TPCS encourages more efficient and secure resource management, enabling scalable solutions that can be adopted by other ports to support the maritime sector's green transition.

This technological transformation goes beyond improving processes; it stimulates a fundamental behavioural shift. The increased environmental awareness among operators leads to greater adherence to sustainable practices and a more future-oriented work culture. These advancements strengthen a resilient port system, capable of tackling environmental challenges and ensuring a lasting positive impact for all parties involved.

6. CONCLUSIONS

A. Success of the green practices

The implementation of the **AR Pilot Navigation Aid** system at the Port of Livorno has demonstrated how the integration of advanced technologies can transform port operations, enhancing safety, efficiency, and sustainability. The adoption of **RealWear HMT-1 smart glasses**, combined with the MONI.C.A. and TPCS digital platforms, allowed port pilots to access critical data in real-time, reducing the margin of error and optimizing manoeuvres. These improvements led to greater precision in operations, reduced fuel consumption and emissions, and more effective coordination among port operators.

However, the introduction of new technologies goes beyond a mere tool upgrade; it also requires a **significant behavioural change** from operators. The success of the system depended not only on the technical effectiveness of the tools used but also on the ability of pilots and tug operators **to adopt new working methods**, based on a more structured and aware use of digital information. In this context, continuous training played a key role in overcoming initial resistance, helping operators understand the benefits of digitization and adapt to an increasingly technological work environment.

Although detailed secondary data on *Key Performance Indicators* (KPIs) is lacking, the qualitative evidence gathered indicates that the introduction of the system had a positive impact not only on operations but also on the mindset of the operators. The use of augmented reality encouraged **greater collaboration and information sharing**, reducing exclusive reliance on individual experience and promoting a data-driven approach. This contributed to a more rational management of resources and an improvement in operational safety.

B. Lessons learned:

The implementation of the AR Pilot Navigation Aid system at the Port of Livorno has provided numerous insights, highlighting both the challenges encountered and the effective solutions adopted to overcome them. This process has revealed important lessons that can be valuable for replicating the model in other port environments:

1. **Resistance to change and cultural barriers.** One of the main obstacles was the initial resistance of port pilots to adopting the new technology. This resistance stemmed from scepticism towards innovative tools perceived as complex or intrusive in established work processes. Additionally, the limited familiarity with augmented reality devices and digital interfaces contributed to slowing the system's acceptance.
2. **Solutions and strategies for overcoming challenges.** To address these challenges, it was essential to adopt a gradual and inclusive approach based on:
 - a. Customized training programs: specific courses aimed not only at transferring technical skills but also at practically demonstrating the benefits of using AR technologies. Simulated operational sessions facilitated a more immediate understanding of the system's functionalities.
 - b. Continuous technical support: the constant presence of technical support reassured operators, reduced the fear of errors, and strengthened confidence in the new tool.

- c. Active stakeholder engagement: ongoing dialogue between developers, pilots, and port authorities allowed the system to be tailored to actual operational needs, fostering greater acceptance.
3. **Importance of digital culture.** The experience demonstrated that the success of technological innovations depends not only on the technical effectiveness of the solutions but also on the ability to promote a digital culture. The need for continuous training to develop widespread digital skills and an innovation-oriented mindset emerged as critical.
4. **Flexibility and adaptability of the system.** Another crucial aspect was the flexibility of the AR system, which allowed the customization of functionalities based on the specific operational needs of the Port of Livorno. This adaptability proved fundamental in integrating the new technology without disrupting existing processes.
5. **Value of interdisciplinary collaboration.** The project highlighted the importance of collaboration among various professionals: engineers, software developers, pilots, and port operators. The interaction between diverse skill sets fostered a more comprehensive and effective approach to the implementation of the technology.

c. Next steps

- Expansion of the system to other Mediterranean ports.
- Development of integrated dashboards for real-time performance monitoring.

Based on the results achieved with the implementation of the AR Pilot Navigation Aid system at the Port of Livorno, several strategic developments have been identified to consolidate the progress made and expand the project's impact on a regional and international scale.

The main goal is to extend the use of the system to other ports in the Mediterranean, adapting it to the specific operational needs of each context. This phase will require a thorough preliminary assessment of the existing technological infrastructure to identify any necessary adjustments and adapt the AR solutions to the different operational dynamics and local regulatory requirements. Promoting collaboration with port authorities and local stakeholders will be crucial to facilitate the integration and dissemination of the system.'

To further improve port operations management, **the development of advanced digital dashboards** is planned. These dashboards will monitor operational performance by collecting and analyzing real-time data on maneuvers, fuel consumption, and environmental impacts. These tools will support strategic decision-making by providing predictive analysis to optimize resources and reduce operational risks. The digital transformation will also require strengthening the skills of port operators through advanced training programs aimed at improving familiarity with AR technologies and integrated digital platforms. Thematic workshops and exchanges of best practices among the involved ports will encourage the sharing of experiences and innovative solutions.

To ensure maximum effectiveness and flexibility of the AR system, it will be essential to integrate it with emerging technologies such as 5G, which will enhance connectivity for faster and more stable data transmission, and artificial intelligence with predictive analytics to optimize operation planning and emergency management.

Through an integrated strategy combining technology, training, and international cooperation, it is possible to promote a safer, more efficient, and sustainable future for the maritime sector.

7. ANNEXES

A. Include relevant supporting materials