MANAGEMENT OF PORT-CITY OSMOSIS: URBAN TRANSPORT INTERMODALITY LED BY AUTONOMOUS VEHICLES

Federica Sortino[1], Andrea Petralia[2], Claudia Lo Vecchio[1], Tullio Giuffrè[1]
[1] University of Enna Kore, Department of Engineering and Architecture, Enna, Italy
[2]Junior Transport Consultant, Civil Engineering, Enna, Italy

Abstract

Cruise passenger flows represent both a challenge and an opportunity to promote the "15-minute city" model. The port of Palermo, a major hub in southern Italy, generates significant traffic and congestion, highlighting the need for improved accessibility, intermodality, and public transport integration within the historic center. The ongoing Palermo Railway Ring project contributes to this objective by strengthening the connection between port and city through an underground metropolitan system. This study applies microsimulation models to analyze pedestrian and vehicular flows across three scenarios: current conditions, post-completion of the metropolitan system, and a future configuration integrating autonomous public transport (CAV). The aim is to assess how metro expansion and autonomous intermodality can reduce congestion, enhance accessibility, and improve urban resilience. Results suggest that integrating autonomous shuttle services can complement fixed-schedule metro systems, offering greater flexibility for cruise passengers and improving port-city connectivity. Furthermore, the research frames the port as a smart urban interface, where digital tools such as IoT, BIM and Digital Twin support data-driven mobility management and infrastructure integration.

Keywords: transport management, intermodal mobility, connected automated vehicles

1 Introduction

The cruise industry has experienced such high growth rates in recent decades that it has attracted sustained attention from the scientific community and industry operators [1]. According to statistics from the CEMAR Agency Network, 2025 is expected to be a record year for the Italian cruise industry. With an expected 14.78 million passengers (a 4.05% increase on 2024) and would consolidate Italy's position as the leading destination in the Mediterranean [2]. A significant number of studies have analyzed the structural characteristics of the global cruise industry. These studies sought to identify the factors that influence the strategic choices of the players involved at all levels of the supply chain [3].
In the European context, Palermo (Italy), occupies a strategic position due to its geographical location, which guarantees its centrality in maritime traffic systems, and its historical role in the development of Mediterranean port networks. The port of Palermo, Sicily's main natural harbor, has historically been the hub of urban development. This has been based on three main areas: digitization of port activities, development of sustainable services and infrastructure upgrades. These strategic trajectories have been designed to increase the operational efficiency and competitiveness of the port system. At the same time, they will contribute to economic and sustainable growth [4].

This article aims to analyze the port-city relationship in Palermo through an integrated reading of cruise tourism flows and needs, urban mobility systems, and existing and upcoming transport infrastructure. The objective is to assess how different infrastructure and service configurations can affect urban accessibility, passenger flow management and the quality of the cruise passenger experience. The study adopts a quantitative approach based on simulation scenarios, aimed at supporting planning strategies geared towards greater functional integration, urban sustainability and resilience of the port-city system.

2 The railway ring as the backbone of intermodality

2.1 The new Palermo Ring Railway as a tool for rebalancing cruise ship traffic flows

The Palermo Ring Railway is a strategic infrastructure project currently under construction. It is designed to create a circular urban metro line, with most of its route being fixed and primarily underground. The 6.5 km long route connects Palermo Notarbartolo station with the city center and the port system, and is a key part of the metropolitan transport network [5]. Its first pathway length involves extending the existing line from the Giachery stop to the new Politeama station, via a new urban section that covers some of the city's main central axes. Several stops are planned along this route, including the Porto stop, the Politeama stop and the future Libertà stop, which will form a new metropolitan backbone connecting the port, the city center and established urban districts. The Porto stop, located along Via Crispi, directly adjacent to the port area, is the central infrastructure hub connecting the port and the city. From a functional point of view, the infrastructure plays a strategic role in directly connecting the port, the city center and the main tourist attractions. In particular, the Porto stop is the hub of the system connecting cruise ship mobility and the urban network, allowing passengers to access the underground network directly without having to take buses or walk, which would increase travel time. In this context, the Ring Railway can be interpreted as a tool for rebalancing cruise flows. The infrastructure enhances urban accessibility, improving access to services, attractions and public spaces beyond traditional tourist routes. In this regard, the Ring Railway aligns with the principles of the 15-minute city, promoting local mobility, polycentric development and reduced reliance on private transport.

2.2 Isochronous analysis of port–city accessibility flows

To support the above considerations, an isochronous analysis was conducted to assess pedestrian and rail accessibility to the main areas of urban interest. The center of the isochrone was placed at the port entrance and the isodistance was set at a time interval that could be covered on foot or by underground in 20-25 minutes. This time interval is considered reasonable and accessible by various user groups for walking, particularly given the time available to cruise passengers during city stops, which is generally between 4 and 8 hours. The study was structured around two comparative scenarios:

- scenario 1: current configuration of pedestrian and rail traffic, prior to completion of the ring railway
- scenario 2: future configuration of travel determined by the entry into service of the complete ring railway.

Figure 1 Walking isochrones (20–25 min) and circular railway route (source: authors' elaboration)

In the first case (isochrone 1), the areas that can be reached exclusively on foot from the port within the time interval considered are represented. This configuration allows access to a significant part of the points of interest, but excludes large portions of the historic center and numerous more distant urban attractions. This has the effect of limiting the spatial extension of the urban experience of cruise passengers. In the second case, relating to the current scenario with use of existing railway infrastructure. The first journey is on foot from the landing point to the Giachery stop, currently the closest to the port area. From here, the railway line allows passengers to reach more distant urban areas; Notarbartolo station was taken as the terminal point of reference for the assessment of subsequent pedestrian mobility. In this configuration, the time available for walking after arrival at Notarbartolo is reduced to about 4 minutes, producing a time compression effect on final urban journeys and reducing the effective usability of urban spaces and attractions. In the third case (isochrone 3), relating to the completion of the Ring Railway, the new Porto stop along Via Crispi takes on a central role in the accessibility system. The direct proximity between the landing point and rail access allows for an immediate connection between maritime mobility and the metropolitan network, eliminating the pedestrian route to the Giachery stop. In this scenario, too, the Notarbartolo station was taken as the reference terminal point for the assessment of subsequent pedestrian mobility, for the same methodological reasons adopted in isochrone 2. This configuration allows for faster access to the inner areas of the city and increases the time available for walking after arriving at Notarbartolo, from approximately 4 minutes to approximately 9 minutes. The analysis shows how the introduction of a railway station directly connected to the port area has a direct effect on expanding the urban space accessible to cruise passengers, improving the continuity of travel, the distribution of flows and the overall usability of the urban system.

2.3 Structural limitations of the Ring Railway for tourist users

Despite the significant contribution of the Ring Railway to improving urban accessibility and rebalancing port-city flows, there are some structural limitations that reduce its specific effectiveness for tourist users and, in particular, for cruise passengers. A first limitation concerns the inflexibility of the railway service timetable. The system operates according to pre-established timetables and scheduled frequencies, currently every 30 minutes. This configuration does not guarantee adequate continuity in relation to the concentrated and intermittent nature of cruise flows, which are characterized by sudden peaks linked to ship docking and disembarkation times.

The isochronous analysis shows that, despite the completion of the Ring Railway, a significant number of stops are outside the 20–25 minute pedestrian isochrones considered compatible with tourist travel on foot. In many cases, stops are located far from the main attractions, requiring additional travel on foot or by road to reach final destinations.
Added to these aspects is the generalist nature of the public rail service, which is not designed to be dedicated to cruise flows. The service may already be saturated when trains arrive at the station, particularly at central stops, limiting access for passengers arriving from the port. This factor introduces a further element of uncertainty into the planning of tourist travel. This is the context for the introduction of autonomous shuttle services (CAVs), designed as adaptive connections between the port system and the urban network, capable of bridging the operational gap between rail mobility and tourist mobility. This framework provides the conceptual and operational basis for the construction of the simulation scenarios developed in this study and for the analysis of the integration between the Railway Ring and autonomous transport systems serving cruise passenger flows.

3 CAVs as a flexible layer of intermodality

In case of concentrated and temporary cruise flows, urban mobility must respond to specific needs related to length of stay, speed of travel and continuity of service. In this context, dedicated mobility services are a strategic component in ensuring accessibility, reliability and quality of the urban experience. The introduction of CAVs into the urban road network plays an important role in transport planning and urban system design. Recent research has focused in particular on the application of autonomous shuttles to urban public transport, highlighting their potential as a tool for integrating existing mobility systems. Studies such as that by Klinkhardt et al. [6] show how autonomous shuttles can enhance the effectiveness of public transport, particularly over medium distances, by reducing access times to services and increasing the attractiveness of public transport compared to private vehicles. Within this theoretical and operational framework, the port of Palermo can be interpreted as a multi-level ITS hub, where railway infrastructure, road networks, pedestrian flows and autonomous mobility interact within a single complex urban system.

3.1 Method: Vissim microsimulation

The initial phase of the simulation method involved integrating the urban network model into the PTV Vissim microsimulation software [13], in order to quantitatively analyze vehicle traffic dynamics and the interaction between traditional flows and autonomous mobility services. The demand modeling has been built by defining the origin/destination (O/D) matrix, calibrated on the basis of the maximum theoretical traffic volumes associated with lane capacity. This approach made it possible to simulate critical operating conditions, representative of the most unfavorable scenarios in terms of service level, congestion and interaction between vehicles. The road network was then modelled under high load conditions in order to evaluate the performance of the system in contexts of infrastructural stress. The assignment of vehicle routes was carried out using the dynamic assignment method, which allows the generation of adaptive routes between network nodes, avoiding static routing schemes and allowing a more realistic representation of route choice behavior [7]. A dedicated vehicle category was defined for the integration of Connected and Autonomous Vehicles (CAVs) into the simulation model. The calibration process should be examined on Giuffrè et al [8]. The simulation was developed by selecting the 'omniscient' behavior type in order to represent a highly efficient CAV scenario. In Vissim, CAV integration was completed by configuring speed distribution functions and driving behavior parameters based on the specifications provided by [9] and the specific hypotheses discussed in [10].

3.2 Simulations, results and discussion

Traffic simulations were conducted on two scenarios in order to assess the effects of introducing autonomous shuttle services on the port-city mobility system. Scenario 0 analyzed the current configuration of the urban network, considering vehicle and pedestrian traffic that affects the movements of cruise passengers leaving the port (figure 2). This scenario represents the actual operating conditions of the mobility system, characterized by high levels of congestion, particularly along the main corridor connecting the port and the city. This road is heavily congested due to the coexistence of heterogeneous flows: heavy port traffic, ordinary urban traffic, tourist flows and pedestrians. During the disembarkation of cruise passengers, interference between vehicle and pedestrian flows further boost congestion, reducing the overall efficiency of the mobility system and increasing travel and waiting times. Scenario 1 introduces an urban route dedicated to AVVs, designed to connect the port's cruise terminal directly with the city center. The corridor uses an existing road section which in the project scenario is assigned exclusively to the autonomous shuttle service. This corridor, shown in yellow in figure 2, constitutes a functional infrastructure dedicated to autonomous mobility, designed to optimize the continuity, regularity and reliability of the service.

Figure 2 Graphical representation of the simulation diagram. Source: authors' elaboration

Two different origin-destination matrices were used, referring to the selected peak hour for an average weekday in the spring/summer period, in order to represent realistic and comparable load conditions between scenarios. The route includes a point of intersection shared with traditional vehicular traffic, in order to test the behavior of CAVs in realistic conditions of interaction with urban traffic. The results also show a slight increase in average speed in Scenario 1 compared to Scenario 0, highlighting an improvement in the overall fluidity of vehicle traffic. Speed variations across the entire simulated network are limited, indicating that the introduction of CAVs does not have a significant disruptive effect on the existing urban traffic system. Moreover, this result indicates that the introduction of autonomous shuttles as a dedicated layer does not generate negative systemic effects, but introduces localized benefits in terms of efficiency, regularity and continuity of service.

Functionally, the results show that introducing a dedicated CAV corridor separates tourist and urban flows, reduces interference between port traffic, urban traffic and pedestrian mobility, and improves journey regularity and reliability.

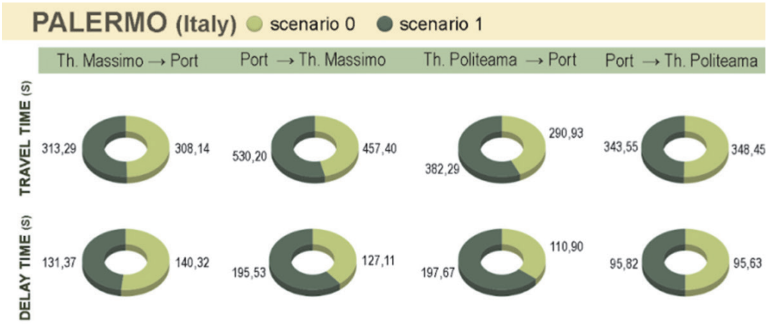

Figure 3 Comparison between Scenario 0 (current situation) and Scenario 1 (with dedicated corridor for CAVs) (source: authors' elaboration)

4 BIM, digital twin and smart port infrastructure outlook

4.1 The port as a digital interface

In passenger ports with high tourist traffic, mobility management no longer depends solely on infrastructure capacity, but on the ability to orchestrate flows through ITS systems and data-driven platforms capable of monitoring vehicle traffic, pedestrian density and travel times in real time. In this sense, the port assumes the role of an advanced information hub, capable of connecting urban transport systems, railway networks and flexible mobility services. In this context, the concept of Digital Twin represents an evolution from traditional static simulation models. A digital twin allows for dynamic correspondence between the real system and the virtual model, enabling predictive analysis, operational monitoring and continuous updating based on the data collected [11]. When applied to the port-city node, this approach allows complex mobility scenarios to be addressed, such as those related to cruise ship traffic concentrated in narrow time windows. In the Palermo case study, this vision reinterprets the port as a smart urban gateway, overcoming the traditional port–city divide and supporting integration with autonomous mobility systems and advanced digital infrastructure.

4.2 BIM-oriented methodological approach for road infrastructure

The research proposes a BIM-oriented methodological approach applied to a strategic road section between the port area, the Ring stations and some major urban attractions. This is to support the integration between the Ring Railway, CAV and ITS systems. The objective is not of a design-executive nature, but rather oriented towards defining a functional representation of the infrastructure, consistent with the requirements of autonomous and intermodal mobility [12]. The approach used focuses on the conceptual structuring of basic infrastructure elements – road alignments, cross sections and spatial relationships between carriageways, pavements and public spaces – interpreted as information entities rather than detailed geometric objects. These entities have been assigned semantics relevant to autonomous driving, such as speed limits, right-of-way rules, traffic light configurations and access restrictions, recognized as key information for supporting CAV systems. The definition of a conceptual level of detail (LOD), which is calibrated on the basis of information quality and infrastructure functionality rather than geometric accuracy, is beneficial for the advanced development of the model. Recent studies demonstrate that, in the preliminary stages, a semantics-oriented LOD is more effective for smart mobility applications than models that are excessively detailed but lacking in operational information.

4.3 CAV and knowledge of the simulated route to the port of Palermo

In the case of Palermo, particular attention is focused on the connection corridors between the port area, the railway network and the main urban attractions. In such conditions, autonomous driving cannot rely exclusively on local, real-time vehicle perception, but requires access to structured knowledge of the route in order to reduce decision-making uncertainty and support more stable and anticipatory travel planning. The integration between CAVs and digital infrastructure allows this knowledge to be articulated on two complementary levels. On the one hand, ex-ante knowledge is based on codified infrastructural information - such as corridor geometry, traffic regulations and operational configurations - which supports vehicle behavior planning before and during operation. On the other hand, ex post knowledge derives from the analysis of operational data collected during system functioning and can be reintegrated into the information system to update and refine operating conditions over time [13].

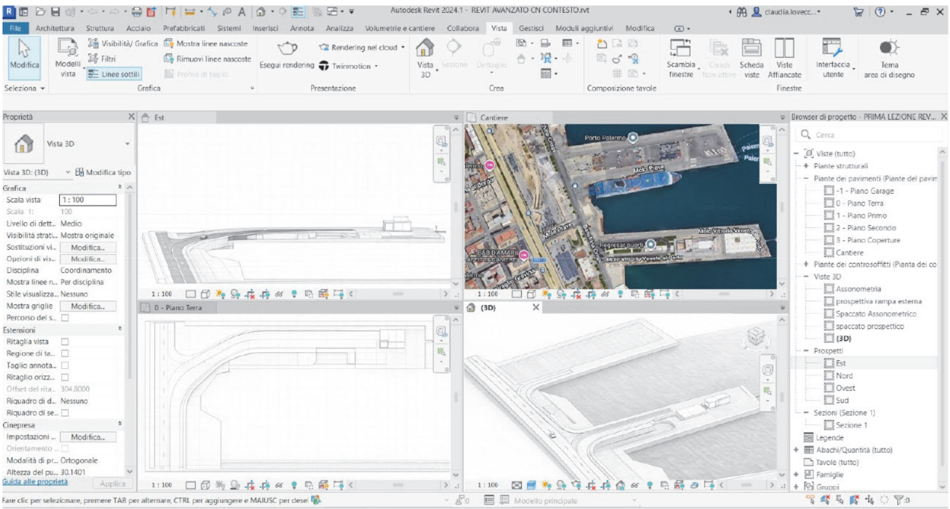

Figure 4 Conceptual BIM representation of the port–city. Source authors' elaboration

In this context, figure 4 shows a conceptual representation of the BIM-based modelling environment of the port–city system modelled. It shows how infrastructural information is structured to support CAV route knowledge and enabling the integration between simulation results and digital road design. Looking ahead, the extension of this approach towards port–city Digital Twin models capable of integrating autonomous ground mobility and Maritime Autonomous Surface Ships (MASS) represents a coherent evolution of current research trajectories, as highlighted in recent studies on smart port cities and urban waterfronts. This perspective opens up scenarios for advanced coordination between land-based and maritime autonomous systems in complex port hubs.

5 Conclusion

It has been argued about the context for the introduction of autonomous shuttle services (CAVs), designed as adaptive connections between the port system and the urban network, capable of bridging the operational gap between rail mobility and tourist mobility. For the case study considered, the system's performance was assessed by measuring specific performance indicators, including levels of traffic congestion, traffic density, waiting times, etc.

Measurements were taken in critical areas of the simulated network, with particular attention paid to urban corridors directly connected to port access and to the routes leading into and out of the port. The study was developed using an integrated approach based on:

- vehicle microsimulation for the CAV and urban traffic components
- isochronous analysis for the pedestrian component.

The results of the simulations confirm that the introduction of CAVs as a service dedicated to cruise flows improves the local efficiency of the mobility system without compromising the overall balance of the urban network. This aspect is particularly relevant in high-traffic port contexts, where the coexistence of urban and infrastructural functions generates high levels of operational complexity. Finally, in order to enhance CAVs shuttle operations in context similar to the one considered, the application of BIM approach to the route modeling could be a strong effort for future road design and management [14].

References

[1] Kester, J.G.: Cruise tourism, Tourism Economics, 9 (2003) 3, pp. 337–350

[2] AdriaPorts: The cruise sector set for a record year: 14.8 million passengers expected in 2025, www.adriaports.com, 02.01.2026.

[3] Abbate, T., Cappello, G., Recupero, A.: Cruise flows: new opportunities for local development, Economia e Politica del Turismo, 2011., pp. 1–18

[4] Giuffrè, T., Petralia, A., Sortino, F., Catania, G.F.G., Lo Vecchio, C.: The development of the port of Palermo and the impact of the new Railway Ring: cruise flows analysis and strategies for urban sustainability and accessibility, Territorializzare il PNRR: Strategie, strumenti e progetti per la rigenerazione della città e dei territori contemporanei, FrancoAngeli, pp. 241–253, 2025.

[5] Ferrovie dello Stato Italiane: Anello ferroviario di Palermo, www.fsitaliane.it, 02.01.2026.

[6] Klinkhardt, C., Kandler, K., Kostorz, N., Heilig, M., Kagerbauer, M., Vortisch, P.: Integrating autonomous buses as door-to-door and first/last-mile services into public transport, Transportation Research Record, 2678 (2024) 2, pp. 605–619

[7] Boje, C., Guerriero, A., Kubicki, S., Rezgui, Y.: Towards a semantic construction digital twin: directions for future research, Automation in Construction, 114 (2020), 103179

[8] Giuffrè, T., Granà, A., Trubia, S.: Safety evaluation of turbo-roundabouts with and without internal traffic separations considering autonomous vehicles operation, Sustainability (Switzerland), 13 (2021) 16, 8810

[9] Chen, C., Seff, A., Kornhauser, A., Xiao, J.: DeepDriving: learning affordance for direct perception in autonomous driving, Proceedings of the IEEE International Conference on Computer Vision (ICCV), 2019.

[10] Huang, J.: Why autonomous driving may finally become reality, Industry Vision – NVIDIA CES Keynote, 2026.

[11] Wang, Y., Zhang, Y., Liu, H., Chen, X.: Digital twin-driven intelligent transportation systems: framework and application, arXiv preprint, 2022.

[12] Zhang, J., El-Gohary, N., Abbas, A.: Semantic BIM for infrastructure asset management and intelligent transportation systems, Advanced Engineering Informatics, 47 (2021), 101236

[13] Sakaguchi, T., Kato, S., Yoshida, T.: Mobility digital twin for cooperative automated driving and traffic management, IEEE Intelligent Transportation Systems Magazine, 2024.

[14] Sortino, F., Lo Vecchio, C.: Smart port-city systems and digital waterfront transitions, Proceedings of the SASBE Conference, 2025.