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NEW CHALLENGES FOR CITIES IN THE TWENTY-FIRST CENTURY

Regenerative Design - Climate Adaptation & Mitigation
Circular Economy - Citizen Agency - Urban Livability

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Dynamic map decision support systems for spatial and mobility planning

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Abstract

Decision Support Systems (DSS) are widely recognized as important tools supporting decision making processes, quite little adopted yet to support sustainable spatial and mobility planning, despite a wide range of literature arising at the turn of the Millennium on Spatial Decision Support Systems (SDSS). This is the case of the e.INS project, which addresses critical challenges in spatial and mobility planning in Sardinia Region (Italy) and provides a methodological approach to develop a sustainable transport model by MaaS solutions. The objective is to propose a DSS architecture to support the Sardinia MaaS, integrating geo datasets relating mainly to demographic and socio-economic aspects, the supply of key services and the provision and demand of transport, the spatial distribution of tourist flows and related externalities to offer a holistic perspective on local and regional transport needs, opportunities, and gaps. Developed using geospatial technologies, the system's operational core is a dynamic dashboard that visualizes key data and performance metrics. The proposed methodology is functional to build a collaborative framework for the DSS, enabling users to update and manage data through a user-friendly interface, thus ensuring its continued relevance and accuracy. This allows local authorities and transport operators to monitor, analyze, and make informed decisions. The system supports the development of a more sustainable, inclusive, and efficient mobility network, ultimately contributing to a smarter future for Sardinia Region.

Keywords

Mobility as a service; Decision support system; Spatial Mobility Planning

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1. Introduction

The new millennium marked a turning point, driven by the rise of Big Data, Machine Learning (ML), and Artificial Intelligence (AI) (Narne et al., 2024) in several research and operational fields such as spatial and mobility planning (Mortaheb & Jankowski, 2023).

The Decision Support Systems (DSS), originally conceived as a "Management Decision System" (MDS) and used mainly in the business and management fields with the aim of supporting managers in strategic and operational activities, are becoming a strategic tool for the governance of cities and regions thanks to these rapid innovations in Information and Communication Technologies (ICT). As a matter of fact, DSS is an interactive computer tool designed to assist decision-makers in tackling complex problems.

Their evolution is closely tied to technological development and the growing need to manage and analyze big data.

The modern DSS manages and analyzes massive volumes of data from heterogeneous sources, including IoT sensors, social media, and mobile data, offering detailed, real-time information on observed phenomena. AI and ML have made DSS "intelligent," capable of formulating suggestions, identifying patterns, and developing predictive scenarios. Cloud Computing has made these solutions more accessible, while improved user interfaces with customizable dashboards and interactive visualizations have increased their usability in various sectors to support decisions in different public policies (Balletto et al. 2018; Ladu, 2020; Kameswari et al., 2025), including the main areas of investigation of the present study, which is part of the "e.INS – Ecosystem of Innovation for Next Generation Sardinia" research project, Spoke 8 - Sustainable Mobility.

The e.INS project addresses critical challenges in spatial and mobility planning in Sardinia Region (Italy) and provides a methodological approach to develop a sustainable transport model by a comprehensive DSS and an innovative MaaS system (Kriswardhana & Esztergár-Kiss, 2023). As a matter of fact, the Sardinia Region, the second largest island in the Mediterranean Sea, represents an interesting case study. Indeed, despite numerous attempts to guarantee territorial continuity (Fancello et al., 2021), geographical isolation still represents the greatest cost for the population of over 1,500,000 inhabitants. Regional disparities can be correlated to a weak extra and intra-regional continuity (mutually shaped), due to a significant gap in transport policies (air and maritime) (Benelli, 2023), as well as in infrastructure and supply for internal mobility, further aggravating the condition of insularity.

In this scenario, the objective of the present study is to propose a DSS architecture to support the development of a Sardinia MaaS. Various geo-datasets relating to demographics, socioeconomics, the supply of key services, transport provision and demand, the spatial distribution of tourist flows, and related externalities will converge on a unique interactive dashboard. The integration and representation of this information will provide a holistic perspective on local and regional transport needs, opportunities, and gaps.

The DSS therefore encourages a collaborative, cross-disciplinary approach to transport planning, enabling users to update and manage data via an intuitive interface, ensuring continuous monitoring, relevance and accuracy.

After this introduction, the manuscript delves into the literature review on the DSS for spatial and transport planning (Section 1.1). Section 2 is dedicated to the materials, and describes the main objective and challenges of the e.INS project to improve the transport system in Sardinia; Section 3 is dedicated to the methodology to develop the DSS architecture to inform a new Sardinia MaaS system, providing a focus on the conceptual framework adopted to develop the multi-level geodatabase (Section 3.1); Section 4 focuses on the main operative results obtained by the e.INS projects, describing in detail the activities carried out to build the multilevel geodatabase to implement the DSS (Section 4.1), the proposal for a ArcGIS DSS dashboard (Section 4.2), the analytical models and predictive capabilities (Section 4.3), and the validation and pilot testing (Section 4.4); Section 5 is dedicated to the discussions and conclusions of the study.

1.1 DSS for spatial and transport planning

The first DSS for spatial planning emerged in the 1970s and 1980s before the proper development and spreading of Geographic Information Systems (GIS). Early Decisions Support Systems in a pre-GIS era addressed spatial issues, also in planning, without relying on a proper and advanced cartographic representation. Early systems relied more on coupling with operations research and linear programming tools, particularly for predicting urban growth, retail location, and transportation impacts. While GIS was initially used to manage and display spatial databases, the need to support complex decision-making processes in spatial planning led to the creation of Spatial Decision Support Systems (SDSS), which integrated GIS functionalities with analysis and modeling components (Reed & Pettit, 2018). The 1990s and early 2000s marked a significant expansion of SDSS capabilities. Increased computational power and more robust GIS software allowed a shift from descriptive to predictive logic. Spatial planning benefitted from the development of SDSS, mainly on aspects related to "information, representation, and modelling, fusing these with more formalized processes of urban planning based on the rational decision model" (Batty and Densham, 1996; Batty et al., 1999). Therefore, DSS for urban planning began to integrate simulation models, multi-criteria analysis (MCA) to evaluate complex alternatives based on multiple criteria and stakeholder preferences (Li et al., 2020), and advanced visualization (2D and 3D) for a better understanding of spatial impacts. The concept of Planning Support Systems, which encompassed a wide range of computer-based tools to support the entire planning process, also began to spread.

The more recent DSS manages various types of Big Data, offering detailed, real-time information on urban dynamics such as vehicular traffic, the supply and demand for services, demographic trends, and more, to support sustainable planning. Within this framework, DSS have found wide applications in spatial planning, with reference to the development of the Smart City model (Papa et al., 2015; Gaglione, 2023; Silva et al., 2024) as they drive decisions on crucial aspects like traffic management, energy optimization, public safety, and the provision of services to citizens. Their ability to provide a dynamic knowledge of urban phenomena is essential for managing urban complexities, such as land-use and unforeseen events such as natural disasters and the impacts of climate change (Papa, 2025).

In the domain of transportation planning, DSS are used for a wide range of applications, from real-time traffic management to the long-term strategic planning of infrastructure, Local Public Transport (LPT) and shared mobility services (Balletto, 2022). These sophisticated tools are affecting a paradigm shift in the management of urban and rural mobility and the very concept of mobility itself, with the transition from purchasing vehicles to purchasing access to mobility services (Janzen et al., 2025). DSS can monitor real-time transport data (from sensors, GPS, mobile phone data) to identify congestion areas, optimize public transport routes, and provide information to travelers, using AI algorithms to suggest alternative routes or to optimize public transport schedules based on demand. In this sense, DSS proves to be fundamental for tackling challenges like decarbonization and reducing traffic congestion (European Parliament, 2020). DSS integrates advanced traffic simulation models to predict vehicle flows, the impact of new infrastructure or changes to the road network, and to evaluate scenarios to inform policies and infrastructure schemes (Papageorgiou et al., 2008) (highways, railways, airports) based on multi-criteria analysis (MCA) and the economic, environmental, and social cost-benefits of different alternatives (Macharis et al., 2009; Balletto et al., 2024b). DSS also finds application in the planning and optimization of logistics networks, from warehouse location to delivery route planning, reducing costs and environmental impact (Turban et al., 2015; Valentini et al., 2023). In this sense, DSSs serve as key tools in MaaS (Mobility as a Service) ecosystems, aiding public authorities and operators in designing sustainable mobility services, managing demand, and monitoring performance through integrated transportation models (Musolino et al., 2022; Concas et al., 2024). As a matter of fact, MaaS (Mobility as a Service) architecture focuses on multi-modal integration and data ecosystems enabling useful tools for trip planning, booking, and payment (D'Amico, 2023). Recent solutions emphasize the importance of considering

AI-driven fusion and public-private collaboration to overcome fragmentation, although many aspects still deserve further investigation (Eze, 2025).

In this perspective, the e.INS project - Spoke 08 - is developing its own DSS with the aim of supporting the implementation of a MaaS (Mobility as a Service) system for the Sardinia region. After Section 2, dedicated to the e.INS project, the DSS architecture is described in Section 3 (Methodology).

2. The e.INS project for sustainable mobility in Sardinia Region (Italy)

The e.INS project, Spoke 8 - Sustainable Mobility, funded by the Italian Ministry of University and Research under the Next-Generation EU Programme (National Recovery and Resilience Plan, is part of the broader scientific debate of sustainable multimodal mobility in the framework of the energy and digital transition (Ladu et al., 2025). The project aims to promote sustainable modal integration in the interconnections between Sardinia Region, Italy and the rest of Europe, and within the same region, applying the Mobility as a Service (MaaS) concept (Hensher et al., 2020; Zhang et al., 2021). The Sardinia Region is the second largest island in Italy, with a population of 1,562,381 inhabitants and a population density value of 64.81 inhabitants/km² (ISTAT, 2025). The Region has a significant deficit in relation to the provision and competitiveness of transport infrastructure (Sardinia Region, 2008). Despite several attempts to guarantee territorial continuity by Public Services Obligations (PSO), the geographical impedance still represents the greatest cost for both inhabitants and city users (Fig.1).

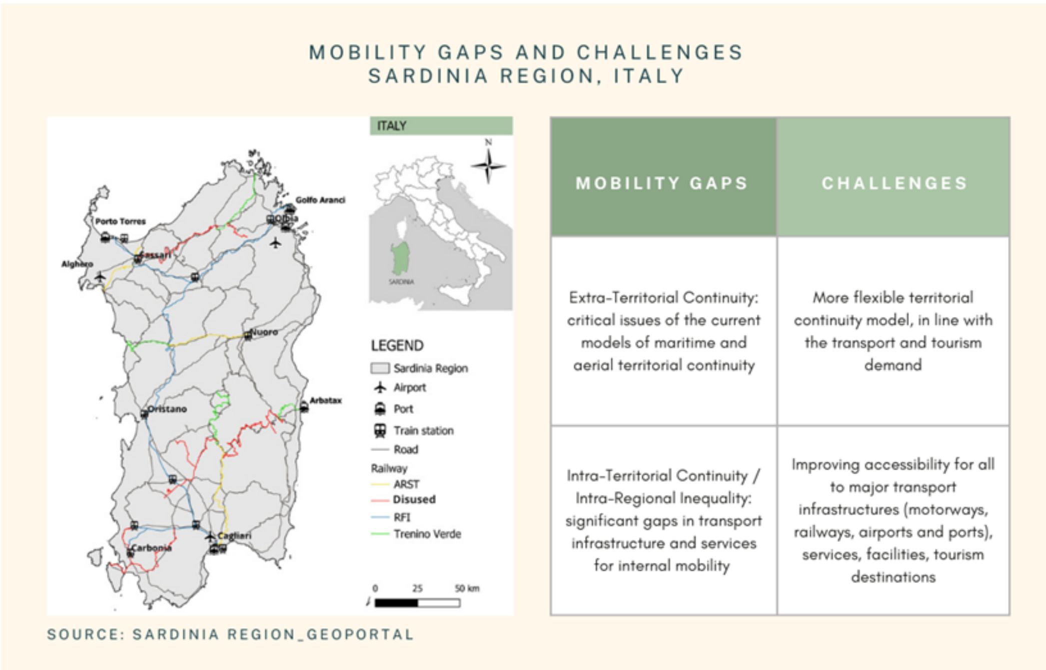

Fig.1 Mobility gaps and challenges in Sardinia (Italy). Author: Mara Ladu

Regional disparities can be correlated to a weak extra and intra-regional continuity (mutually shaped), due to a significant gap in transport policies (air and maritime), as well as in infrastructure and supply for internal mobility, further aggravating the condition of insularity (CRENoS, 2023). As a matter of fact, Transport services are limited to a few rail connections due to the limited extent of the network, as well as public transport routes on extra-urban roads operated by the regional company ARST and a few private, subsidized companies. Urban public transport is available in major cities. The island's settlement structure, characterized by smaller centers that depend heavily on main urban areas, determines the structure of transport services. These services become sparser in terms of trips and frequency further away from main attractions you go, making public transport less convenient and less competitive with private cars. In this sense, the past, present and future of the Sardinia Region are closely linked to the "transport" issue, due to the lack of continuous external connections and, above all, the lack of internal connections within the island. The transport system has significantly influenced various development opportunities (Fancello, 2022), as well as the rise of tourist destinations, which nowadays face seasonal concentration of tourist flows (Balletto, 2024a; 2025a). In this sense, the quality of transport infrastructure and services (road, rail, maritime, and air transport) is a key factor in reducing travel times and improving internal connectivity (European Parliament, 2024).

Within this framework, regional issues and regional disparity are at the core of the e.INS project. The analysis of the Sardinia transport system to encourage a modal shift from private cars to more sustainable modes of transport represents a fundamental research activity. Emphasis is placed on accessibility to Sardinia airports - the main passenger gateways to the island - to promote the integration of mobility services, supported by digital platforms for both management and use.

Within this framework, the integration between urban planning, transport systems and ICT represents a prerequisite for a multimodal transport model that combines mobility demand and supply with which to inform a MaaS system. In this perspective the research project envisages several stages, including activities and associated milestones. Among these, the present study focuses on the methodological approach adopted to create a multi-level geodatabase concerning transport supply, land use and the spatial distribution and provision of urban and territorial facilities. This structured knowledge base is essential for developing a sustainable, multimodal transport model for Sardinia's airports based on the MaaS concept that can meet the needs of residents, tourists, and city users. In this process, Decision Support Systems (DSS) are useful tools for supporting the formulation and validation of the innovative mobility system.

3. Methodology. The DSS architecture for a Sardinia MaaS system

The present study proposes an innovative DSS architecture with the aim of supporting key mobility ecosystem actors (authorities, public and private transport operators and mobility providers) in the design and implementation of a DSS for a Sardinia MaaS (Mobility as a Service) system, in line with the e.INS project - Spoke 08 – objectives.

According to the literature review (Arampatzis et al., 2004; Turban et al., 2010; Zak, 2010; Ocalir-Akunal, 2016; Sharda et al., 2019), DSS integrates data, models, and a graphic interface. The system is composed of the following subsystems: a Database Management subsystem responsible for the storage and management of large volumes of data; a model base subsystem the purpose of which is the processing of information by way of data mining techniques, algorithms, mathematical and analytical models; and a graphic user interface which provides a user-friendly, flexible, and interactive visualization of data and analytics.

Based on the way data is received and processed there are different categories of DSS (Salanova et al., 2022):

1. Communication-driven decision support systems, frequently employed to facilitate effective collaboration between internal teams within an organization via a web or client-server.
2. Data-driven decision support systems which have been proven to be beneficial in the process of querying a database or data warehouse.
3. Document-driven decision support systems utilized for the purpose of searching web pages and locating documents on a specific set of keywords or search terms via the web or a client/server system.
4. Knowledge-driven decision support systems which furnish specialized expertise and information for addressing specific problems and provide decision makers with assistance by leveraging various data mining techniques, including neural networks, fuzzy logic, evolutionary algorithms and case-based reasoning as well as artificial intelligence.
5. Model-driven decision support systems which rely on mathematical and analytical models to facilitate the analysis of decisions or the selection of different alternatives.

Fig.2 illustrates the current and prospective architecture of the Sardinia MaaS system's DSS. The proposed DSS is principally composed of two elements: the database management subsystem and the graphic user interface. This structure enables computations on data retrieved from the database management system and facilitated by the spatial analysis tools provided by Geographic Information Systems. It also allows for the inclusion of a transport model management subsystem that provides analytical and predictive functions, such as planning travel itineraries, optimization algorithms, demand forecasting, scenario analysis, evaluation, and more. Together, these subsystems form the knowledge base management system of the DSS, providing integrated, structured information to inform decisions regarding the transport system and its management.
According to this architecture and the DSS classification, our DSS is data-driven (2). With the addition of the model subsystem, it will also be classified as model-driven (5). Furthermore, the incorporation of GIS functionalities makes it a GIS-based Decision Support System.
Operationally, the DSS collects and systematizes a multi-level geodatabase functional to develop a demand and supply model for sustainable multimodal transport to and from Sardinia's airports, with the resulting knowledge base feeding into an airport MaaS system.

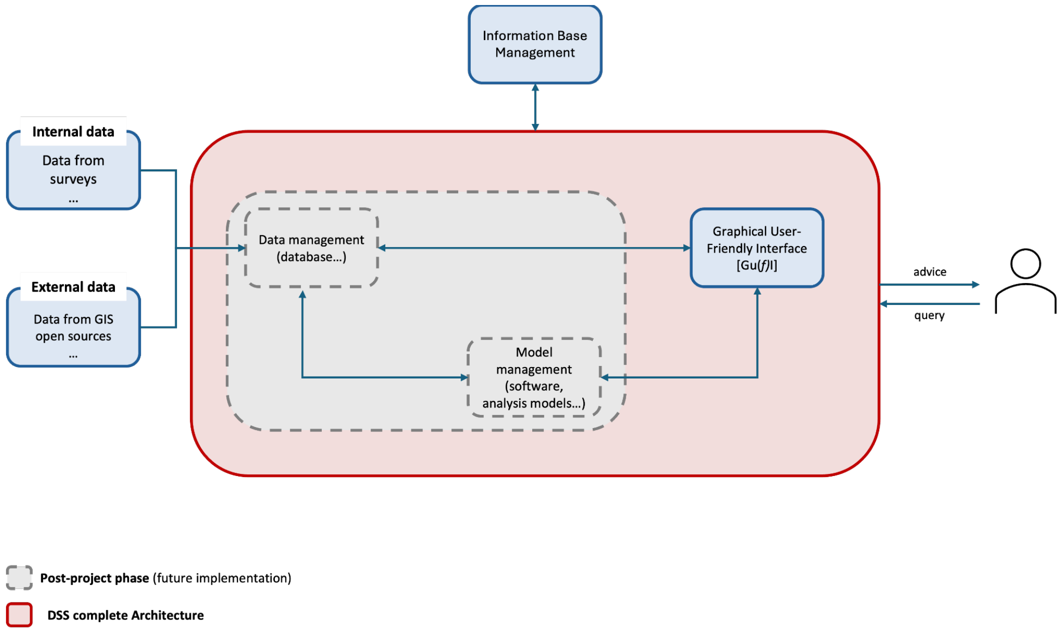

Fig.2 Current and prospective DSS architecture for a new Sardinia MaaS system. Authors: Tanja Congiu and Sara Faedda

3.1 The conceptual framework

The conceptual framework of the multi-level geodatabase is reported in Fig.3.
The construction of the database is divided into the collection and systematization of information (open data, static and real time) relating to various topics that characterize the Sardinian organization of settlement, socio-economic system (with particular attention on the spatial distribution of tourism flows), and the provision and demand of transportation services. The operational scheme is as follows: Data (code, name, source), Spatial dimension (unit and global dimension), File (format, date, and frequency update). The cartographic bases used are: Open Street map, Google Earth, MyMaps, etc. with the network of roads, railway and internal maritime routes also represented.
The multi-level database, that is preparatory for the construction of a demand (local community and city user) and supply model for sustainable multimodal transport in Sardinia, also includes the results of network analysis techniques provided by the GIS software using the data collected.
GIS-based DSS supports the holistic approach to LU&Transport planning (Geertman & Stillwell, 2009). More precisely, tools like ArcGIS are ideal for building DSS that support integrated spatial and transport planning.

Its advanced capabilities for spatial analysis, modeling, and visualization allow for the overlaying of zoning maps, transport networks, demographic data, and environmental data.
Network Analyst (for routing optimization and accessibility calculation), Spatial Analyst (for proximity and overlay analysis), and Geostatistical Analyst techniques make it possible to visualize and analyze spatial disparities (Ladu et al., 2024; Ladu & Balletto, 2024) and to accurately quantify the impacts of new infrastructure and different policies. These functionalities are testing as part of the e.INS project, Spoke 8 - Sustainable Mobility, which uses both the ArcGIS Desktop Software to create, analyze, and share multidimensional databases (social, economic, demographic, land use, transport) for the regional context of Sardinia, and the ArcGIS Dashboard web application, which allows for the development of dynamic and easy-to-understand presentations for a wider audience. In particular, the DSS is functional to the development of an airport MaaS for a more efficient, sustainable, and user-responsive transport system to and from Sardinia, promoting intramodality in internal and external connections.

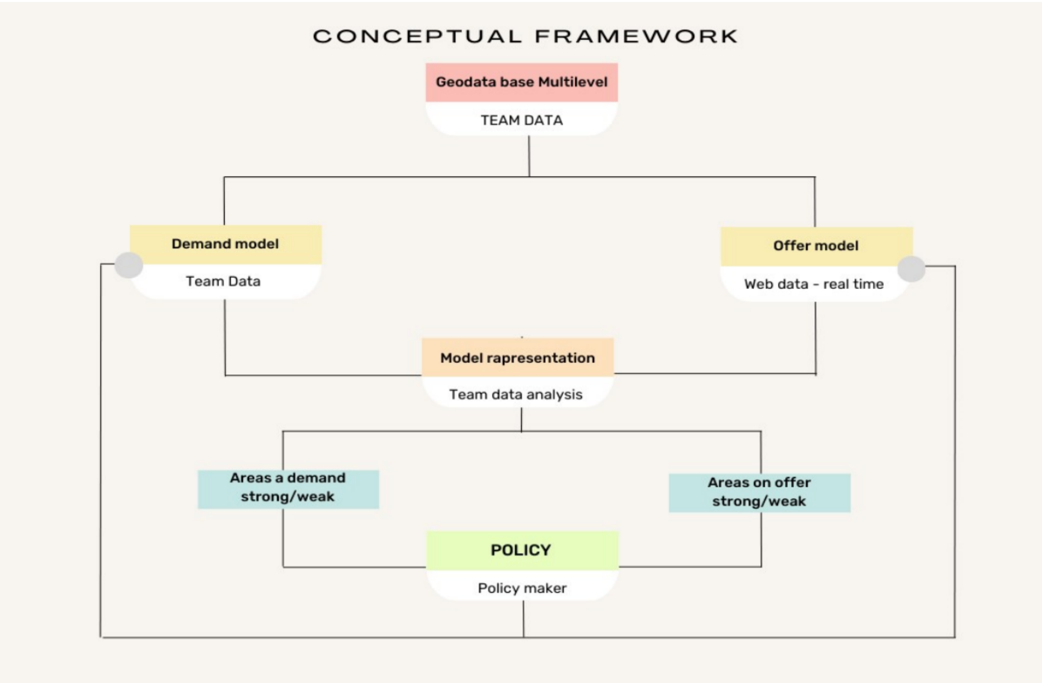

Fig.3 Dashboard framework to support MaaS system. Author: Ginevra Balletto

To enhance the clarity of the DSS development process, the system workflow can be represented using Business Process Model and Notation (BPMN 2.0) standards. The workflow follows these key steps:

1. Data Collection and Ingestion: Data from heterogeneous sources (open data portals, transport operators, IoT sensors, surveys) are collected and validated;
2. Data Processing and Cleaning: Raw data undergoes standardisation, format conversion, and quality assurance in the Database Management subsystem;
3. Storage in Multi-Level Geodatabase: Processed data is organized in the Information Base Management system, structured by topic and spatial/temporal dimensions;
4. Spatial Analysis and Modeling: GIS tools (Network Analyst, Spatial Analyst) perform analysis on the stored data, generating derived indicators and metrics;
5. Visualization and Dashboard Generation: Results are rendered in the ArcGIS Dashboard's graphic user interface as interactive maps, charts, and indicators;
6. Decision Support and Scenario Evaluation: Users interact with the dashboard to explore scenarios and generate insights for policy decisions. (Future step): Model-based predictions and optimization analyses provide recommendations.

4. The operative results. From the dataset to the dashboard

4.1 From data to DSS

A comprehensive framework of the multi-level geodatabase is provided in Fig.4. The figure illustrates the main topics selected for the achievement of project milestones and the interconnections among the following analytical dimensions:

1. Dynamics of passenger demand (temporal and spatial patterns of movement to/from Sardinia).
2. Land use (spatial distribution of services, facilities, and economic activities in Sardinia).
3. Extra-Regional Transport Connectivity (air and maritime connections connecting Sardinia to mainland Italy and Europe).
4. Intra-Regional Transport Supply (public and private transport services within Sardinia).

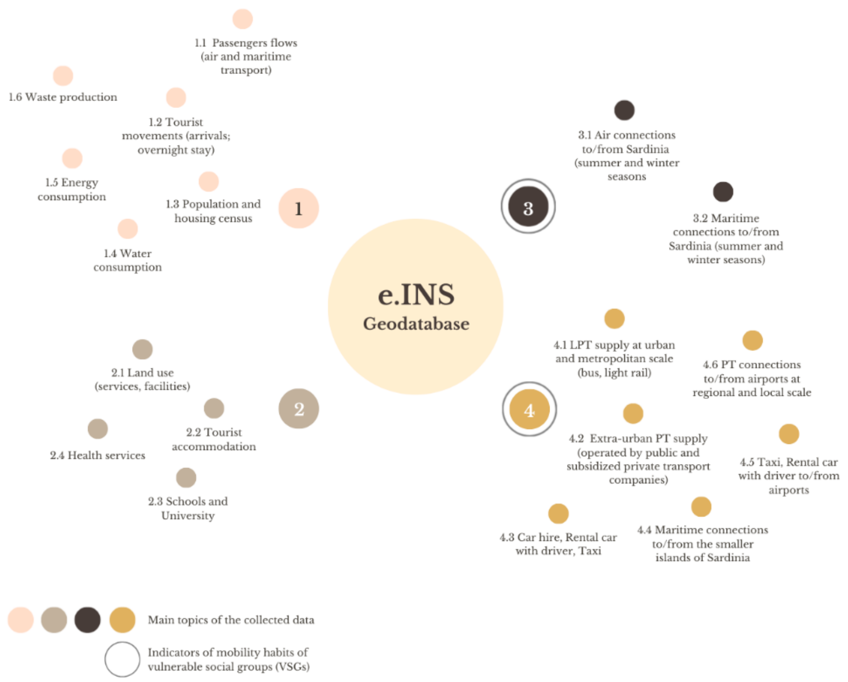

Fig.4 Framework of the multilevel geodatabase. Authors: Ginevra Balletto and Mara Ladu

More precisely, as regard 1) and 2), the list of the main topics of the collected data is reported below: Urban services and productive activities; Population and housing census; Local labor systems; Incomes; Consumption of water and electricity by sector; Urban waste production; Passenger traffic (air and maritime transport); Tourist movements (arrivals and presences); Accommodation facilities (number and type of tourist accommodation facilities); Education (schools and University); Health services (number of hospital beds; type of hospital emergency network structures).

Regarding 3) and 4), the list of the main topics concerns the depiction of the transport supply to and from Sardinia and within the island. The following data were therefore collected and processed: data on air and maritime connections to/from the main Sardinian gateways for the whole year; measurement of the infrastructural network capacity and connectivity; coverage and frequency of transport services (considering both public and private operators); accessibility of the main transport nodes (airports at first - and urban amenities). The spatial analysis of the road network and supply of mobility services (public and private) in the Sardinian regional context revealed various inequalities in access to main gateways and destinations between areas.

In addition, the analytical dimensions of the multilevel geodatabase are interconnected through cross-cutting analytical themes, including socioeconomic characteristics, accessibility patterns, and the specific needs of vulnerable social groups (Sahin et al., 2025). More precisely, a set of indicators of mobility habits of vulnerable social groups (VSGs) that represent a cross-sectional investigation element for aspects 3) and 4) of the geodatabase (Fig.4). This knowledge base supplements the travel demand database, enabling user profiling and customised mobility services. For example, depending on user preferences and needs, the DSS can provide evidence of specific transport service characteristics, such as wheelchair accessibility or assistance with changing between modes of transport. The main aim is to ensure that the needs of passengers with reduced mobility are considered when planning travel options. At the same time, the specific characteristics of the areas connected can be highlighted to identify viable, efficient solutions, such as supplementing regular transport services, in areas with low demand, with integrated, personalized mobility options that reduce isolation and contribute to territorial equity.

The DSS's graphical interface also offers advantages. For example, the provision of up-to-date information, made possible by mobility data sharing from transport operators, is particularly beneficial for all users, including planners, transport management operators and final users, especially those who are less familiar with the area, such as tourists and people with special needs.

The adoption of the "accessibility for all" approach in the design of a MaaS platform will require the incorporation of the data collected in the DSS.

4.2 Proposing a DSS dashboard

The multilevel geodatabase defined in the first phase of the project for analyzing and monitoring sustainable mobility in Sardinia, as well as to develop innovative mobility models and tools, has been essential to implement a DSS to support sustainable mobility and transport planning in Sardinia.

The DSS was initially designed as a web-based solution, developed using standard web technologies like HTML, CSS, and JavaScript. This approach offered flexibility for custom development; however, during the early phases of the project, the decision was made to transition to the ArcGIS platform to leverage mature geospatial functionality, enterprise-level infrastructure, and integration capabilities with existing systems used by regional stakeholders. This technical migration represented a significant architectural decision, balancing customization capabilities against production-readiness and stakeholder familiarity.

As a matter of fact, ArcGIS, developed by Esri, is a world-leading Geographic Information System (GIS) platform characterized by flexible approaches that enable the collection, integration, connection, connection, creation, analysis, management, and sharing of spatial data. Widely used in urban governance, among professionals and public organizations, ArcGIS supports sustainable development initiatives, including monitoring and managing natural and environmental resources, risk analysis and mitigation, transportation and logistics planning, market analysis, transparency in decision-making, and public safety. In this context, ArcGIS is a critical tool for achieving the objectives of the e.INS project.

Within the e.INS project, both ArcGIS Desktop software (Esri, ArcGIS for desktop) (Fig.5) and the ArcGIS Dashboard (Esri, ArcGIS Dashboards) web applications (Fig.6 and 7) were employed. The desktop software was used to create, analyze, and share intelligent maps and spatial data.

Moreover, ArcGIS offers free access to additional databases to implement the analyses carried out by the e.INS project such as What-if Analysis to support multi-level and cross-sectoral governance in transport planning and data-driven decisions. From a system architecture perspective, the DSS adopts a centralized geospatial data management approach based on ArcGIS services.

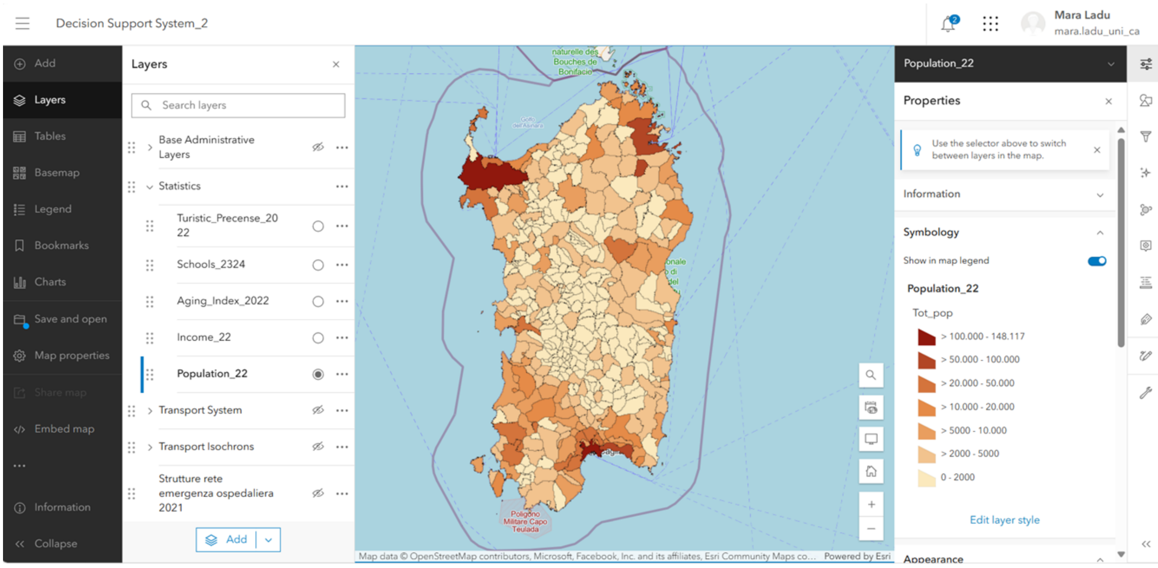

Fig.5 Spatial distribution of population in Sardinia (2022) - ArcGIS Desktop software. Authors: elaboration by all authors

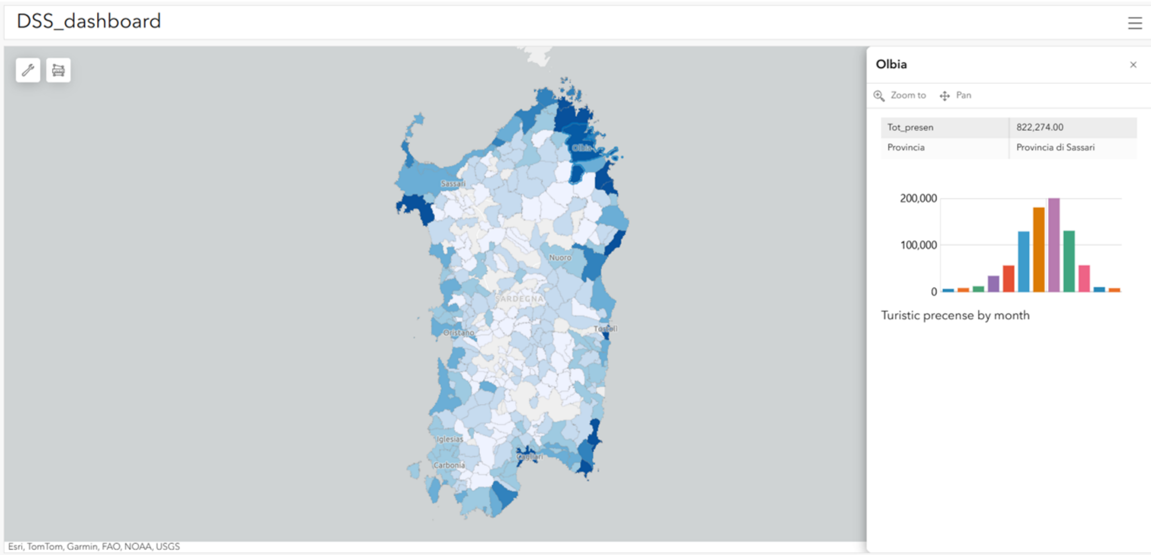

Fig.6 Tourist presences by month - ArcGIS Dashboard web application. Authors: elaboration by all authors

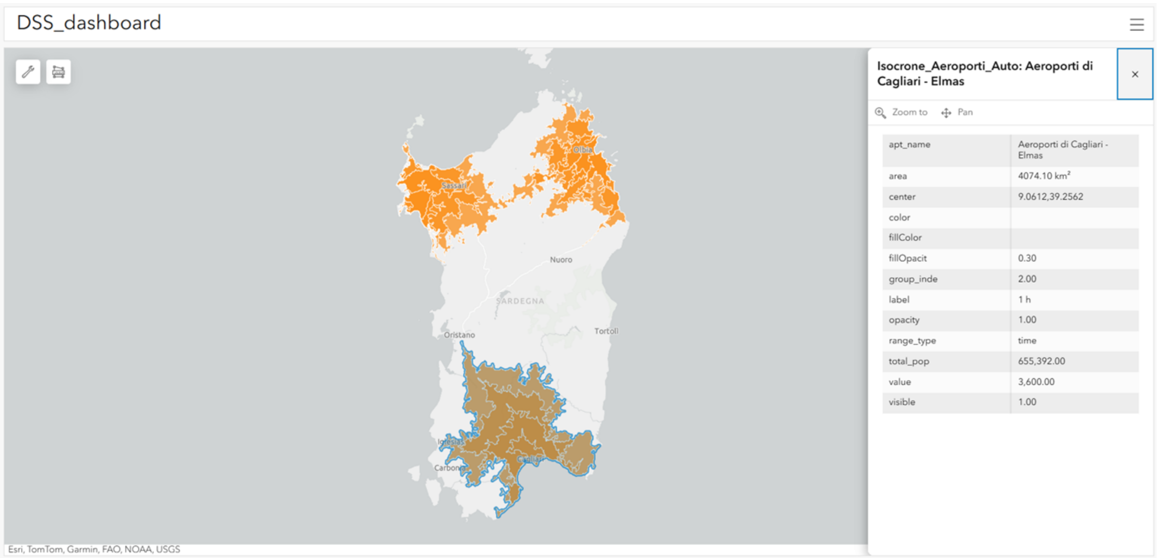

Fig.7 Sardinian Airports' isochrones by private car Travel Time: 15, 30. 45. 60 minutes - ArcGIS Dashboard web application. Authors: elaboration by all authors

Spatial datasets are processed in the ArcGIS Desktop environment and published as hosted feature services within the ArcGIS cloud, which are directly consumed by the web-based dashboards, ensuring consistency between analyses and visualizations. Data synchronization is managed through service-based updates, allowing controlled overwrite or incremental updates so that dashboards automatically reflect changes with minor reconfiguration. Data storage and security rely on ArcGIS-managed cloud infrastructure with role-based access control, ensuring differentiated user permissions, protection of sensitive information, and compliance with public administration data governance requirements. The ArcGIS Dashboard web application leverages data produced and managed in the desktop environment to create dynamic, user-friendly visual presentations for a broader audience. As a matter of fact, one of the critical success factors for the DSS is ensuring that it meets the distinct informational and decision-making needs of different stakeholder groups.

Stakeholders in the transport planning process include transport technicians, urban planners, transport operators and private mobility providers, as well as policymakers and administrators. The latter requires executive summaries, key performance indicators (KPIs), cost-benefit analyses, and scenario comparisons.

To effectively support these diverse groups, DSS implementation includes communication strategies such as multiple visualization formats for data and customizable filters and drill-down capabilities to explore data at multiple levels of detail. More precisely, the proposed dashboard offers an integrated view of geographic data through various interactive visualizations—maps, lists, charts, tables, and indicators—that allow users to monitor events, identify trends, share analyses, and develop predictive scenarios. This comprehensive overview facilitates timely and informed decision-making with a variety of analytical tools readily available. Specifically, within the ArcGIS-based phase of the project, queries constitute a fundamental component allowing easy filtering and data visualization. The users can dynamically explore the dataset by applying customized filters, selecting geographic areas of interest, or isolating particular indicators.

For example, Fig.8 shows that in the 2022 Population layer, it is possible to filter and display only those communities with at least 5,000 inhabitants.

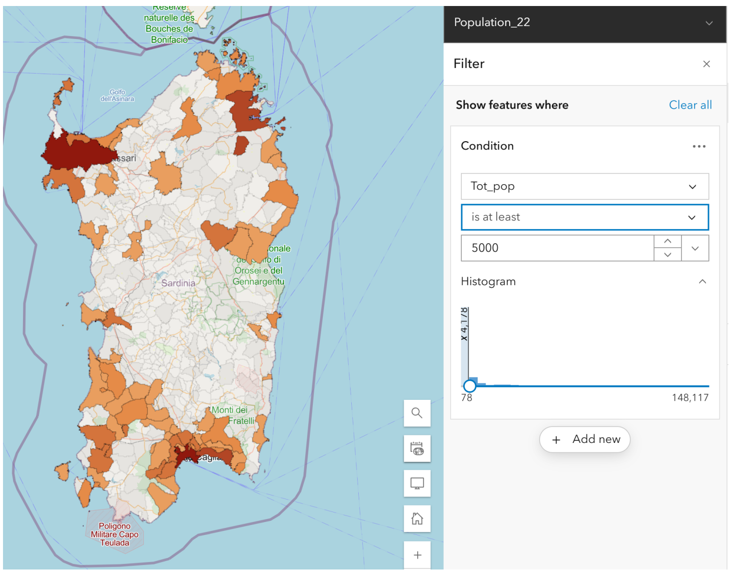

Fig.8 Sardinian Population (2022) filtered municipalities with at least 5,000 inhabitants. Authors: elaboration by all authors

Such interactive capability enables engaging navigation with insights tailored to the user's needs. As a result, decision-makers can rapidly assess the impact of various mobility strategies or environmental factors through real-time data manipulation. Moreover, the ArcGIS platform offers strong mechanisms for handling and incorporating new or updated data. The solution remains reliable without complete redevelopment or downtime, where users can efficiently update the datasets from external sources, field data collection, or periodic surveys, and automatically incorporate them into existing maps, dashboards, and analyses. Such a level of flexibility is essential for maintaining the relevance of the tool in a dynamic development environment such as sustainable mobility planning.

In terms of data sharing, ArcGIS has a complete suite of options for distributing geographic information and analytical results across multiple channels. The web-based interface ArcGIS Dashboard facilitates broad dissemination to diverse audiences, ranging from technical experts and policymakers to the general public, maximizing the DSS impact. These platforms enhance understanding and support transparent decision-making processes through intuitive, visually rich presentations of complex spatial data. Additionally, ArcGIS allows administrators to define multiple user roles, clearly define permissions, and integrate robust access control to protect sensitive information while encouraging collaboration among stakeholders.

ArcGIS is widely used in public administration, making it an ideal system to share with final users such as local governments, public transport operators at local and regional levels, and various stakeholders involved in transport planning. These end users will be able to edit and update the dataset, ensuring that the DSS remains a living tool adapted to evolving needs.

The current DSS shows the data set created during the e.INS project by the research team:

- Dataset relating to the regional socio-economic context, with particular attention on the spatial distribution of tourism flows;
- Dataset relating to the Provision and Demand of Transportation Services;
- Geospatial analysis of regional dynamics using the data collected and applying specific network analysis techniques.

4.3 Analytical models and predictive capabilities

The current implementation of the Decision Support System (DSS) integrates a diverse set of analytical tools and modeling functions designed to assess accessibility, spatial disparities, and transport demand dynamics.

A key component is the network analysis module, which evaluates accessibility through two primary approaches (Palermo et al., 2025). First, isochrone analysis employs ArcGIS Network Analyst to generate travel time polygons from key transport nodes such as airports, ports, and railway stations. These polygons, calculated for multiple travel time thresholds (15, 30, 45, and 60 minutes by private car), identify areas characterized by low accessibility under different transportation modes and scenarios. Second, service area analysis maps the spatial coverage of public transport services, detecting both underserved regions and redundant overlaps.

The spatial disparity analysis framework overlays transport infrastructure with socioeconomic and demographic indicators to highlight geographic inequities in mobility. Overlay and clustering techniques identify localities where vulnerable populations encounter limited travel options and reveal spatial patterns of service concentration or unmet demand (Di Ruocco, 2025).

In the current development phase, the DSS also provides demand characterization tools. These include a tourist flow analysis module, combining data on accommodation capacity, seasonal occupancy, and travel records to describe the spatial and temporal distribution of tourist mobility. Additionally, population and service proximity indicators measure distance-based accessibility between settlements and key facilities, healthcare, education, and employment hubs—supporting comparative analyses of service access.

A dedicated model management subsystem is being developed to enable predictive and optimization functionalities. Planned models include:

- Demand forecasting models based on machine learning regression techniques applied to historical passenger and tourist data, enabling short- and medium-term predictions of transport demand by origin-destination pair;
- Routing optimization models using integer linear programming to design efficient public transport routes that balance demand coverage, service costs, and equity objectives;

- Multi-Criteria Analysis (MCA) for evaluating policy alternatives against multiple dimensions—economic, environmental, and social—through a weighted aggregation approach.

These modeling capabilities will be operationalized in the next project phase, accompanied by full documentation of assumptions, inputs, parameter settings, and validation metrics.

4.4 Validation and pilot testing

A pilot case study was implemented focusing on airport accessibility and tourist mobility planning in Sardinia to assess the operational performance of the DSS. The test examined the region's three main international airports—Cagliari, Olbia, and Alghero—to evaluate how the DSS supports strategic planning decisions such as defining optimal shuttle routes and frequencies connecting tourist accommodation zones with airports, minimizing travel times while controlling operating costs.

The pilot integrated data on tourist accommodation, seasonal occupancy trends, and existing transport connections within the DSS. Isochrone analyses identified clusters of accommodation facilities located beyond a 30-minute travel radius from the nearest airport. These clusters were cross-referenced with tourist arrival data and public transport availability to detect service gaps.

Results indicated several poorly served areas, particularly in the Costa Smeralda region, where access to Olbia Airport exceeded 45 minutes by public transport. The DSS dashboard visualizations enable stakeholders, including the regional transport authority, tourism operators, and airport managers, to interactively explore demand concentrations and accessibility gaps. Preliminary route optimization simulations suggest that the introduction of two to three dedicated shuttle lines during peak tourist seasons could reduce average airport access times to under 30 minutes for approximately 85% of total accommodation demand, with clear implications for cost efficiency.

A DSS performance test will be performed to confirm that it meets the usability and reliability standards required for operational decision support in real-world transport planning contexts, supporting simultaneous access by multiple users and ensuring fast query response times for standard analytical operations.

5. Discussion and conclusions

As part of the e.INS project, Spoke 8 - Sustainable Mobility, the DSS and the future dashboard are intended as intelligent tools that can integrate a set of data to analyze regional development dynamics. It focuses on the accessibility of local communities to the main transport infrastructures (airports, port and railway stations) and key services to support policy makers in their decision-making processes and create predictive scenarios. As a matter of fact, based on the analyses developed within the e.INS project, which revealed inequalities between areas in terms of transport provision, together with the distribution of demand, the DSS supports planning new solutions: it could predict mobility demand in specific areas, forecast transport supply (public and private), optimize routes, thus promoting the transition to sustainable mobility models.

In this context, the identification of all possible public and private transport options plays a primary role to develop an airport MaaS system. By using the collected indicators, the DSS will be able to predict tourist flows and mobility demand, allowing operators to proactively adapt their transport offerings. The DSS will also make it possible to evaluate complex scenarios by simulating the environmental (e.g., CO_2 emissions), economic, and social impact of new policies or proposed infrastructures aimed at promoting sustainable intermodal connections.

From a social impact perspective, the e.INS project aims to ensure social inclusion by integrating data on the needs of Vulnerable Social Groups (VSGs) into the DSS to design mobility systems that reduce inequality, in line with the concept of accessibility for all. Moving from theory to practice, this involves the creation of personalized routes and services, particularly for people with reduced mobility. This design choice is a precondition for making airport MaaS a tool to promote regional equity.

Finally, the development of an interactive ArcGIS Dashboard with an intuitive user interface will make the DSS more accessible and understandable to stakeholders.

As demonstrated in Section 4.2, the DSS implementation incorporates explicit communication strategies and role-tailored visualizations to ensure that diverse stakeholder groups - from technical experts to regional administrators - can effectively engage with the tool and extract decision-relevant insights. This will facilitate public participation in decision-making processes, thereby improving governance transparency and effectiveness. Final users will be able to update or implement datasets directly through the ArcGIS Online environment or connected enterprise portals, using secure login credentials and role-based permissions. Editing can be performed via the ArcGIS Dashboard's linked web maps or dedicated ArcGIS Web AppBuilder applications, which allow point-and-click editing of geographic features, modification of attribute tables, and batch uploads of CSV, shapefile, or GeoJSON datasets. Data changes are instantly saved to the underlying hosted feature layers, ensuring that updates are immediately reflected in all connected maps and dashboards. Version control and edit tracking are enabled to log modifications and preserve data integrity, while administrators can validate updates before publishing them to the public-facing DSS. This workflow allows local authorities and transport operators to keep datasets current without requiring intervention from the development team, thus maintaining a dynamic and participatory system.

The current DSS is at Technology Readiness Level (TRL) 5-6, representing a tested and validated system in a relevant environment. The system has been prototyped using actual datasets from Sardinia's transport and territorial systems, and the ArcGIS-based implementation has been piloted with regional stakeholders. While operational for data analysis and visualization, the system is not yet deployed in full production use with continuous real-time integration from all regional transport operators. The transition to TRL 7-8 (system prototype demonstration and ready for deployment) will be achieved upon integration of the Model Management subsystem, full automation of data synchronization, and operational integration with transport operator systems for real-time data feeds. AI/ML algorithms will be considered as significant drivers for modern DSS to develop the proposed workflow.

Moreover, the DSS will include additional datasets related to the transport system supply, considering the most recent forms of Advanced Air Mobility (AAM) and drones, which are defining new transport systems. As a matter of fact, advanced mobility systems, and, more precisely, advanced aerial mobility systems, promise to adequately address the need for efficient transportation in sparsely populated areas, such as those that characterize the Sardinia region, providing efficient connections to inland and mountainous locations far from the main road network, as well as to smaller islands. The use of advanced mobility systems has the potential to become an effective solution for those areas that are otherwise challenging to reach by conventional means of transportation, especially regarding healthcare and emergency transport needs.

These aspects will be included in the DSS as key elements for supporting the implementation of new infrastructures and hubs that require strong integration with spatial planning and sustainable urban mobility plans, capable of ensuring accessibility, intramodality and integration with the territory.

More precisely, the DSS will be essential for managing the use of drones and air vehicles in urban settings, supporting the planning of vertiports (identifying optimal locations and integrating them with the existing transport network), optimizing routes, and managing interference with traditional air traffic, especially for emergency services and for connecting marginal areas, such as in the Sardinia region.

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M.L. and G.B. wrote Section 1, Section 1.1, Section 3.1 and Section 5; M.L. and G.F. wrote Section 2; M.L., G.B. and T.C. wrote Section 3 and Section 4.1; M.L., and E.F.P. wrote Section 4.2; G.B. wrote Section 4.3 and Section 4.4. All authors have read and agreed to the published version of the manuscript. During the preparation of this work the authors used AI-assisted technologies in the writing process

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