Modal Choice for High-Speed Railway Systems: The Italian Case Study

Giuseppe Musolino, Marialuisa Moschella, Francesco Russo(✉), and Domenico Sgro

DIIES, Università Mediterranea of Reggio Calabria, 89100 Reggio Calabria, Italy
francesco.russo@unirc.it

Abstract. High-Speed Railway (HSR) systems have established worldwide for their technical characteristics, which wherever they are built have allowed greater economic, social and environmental sustainability of transport. 60,000 km of HSR in operation and 60,000 km under construction or design testify to the increasing importance of HSR systems. For the planning of new lines and for the monitoring of the current ones, it is necessary to have knowledge of modal choice that allow us to evaluate the goodness of the infrastructure investments and the validity of the services offered to users. To this end, it is essential to collect data on users' choices in the current situation.

The overall results obtained provide valuable insights for understanding current transport flows and provide a basis for analysing future trends resulting from the introduction of new HSR lines in southern Italy.

The effectiveness of the HSR system depends on the consistency between technical planning and design choices and international standards. Verifying this consistency is made possible by an in-depth analysis of demand, carried out using mobility data. The preliminary results obtained represent a first step in this direction.

Keywords: High-Speed Rail (HSR) · Sustainability · Demand · Modal Choice

1 Introduction

In the context of the 2030 Agenda's sustainable development goals, the planning of high-speed rail (HSR) infrastructure is a key factor to achieving more sustainable mobility, with implications on the socio-economic aspects, increasing the economic competitiveness of the connected regions, and on environmental aspects by promoting a more energy-efficient mode of transport contributing to the European Green Deal's target of reducing transport sector emissions by 2050 [1–11]. In specific regions such as Greece, southern Italy and Eastern Europe, where per capita GDP is below the European average, high-speed rail lines have been recognised as infrastructure solutions for reducing inequalities caused by limited connectivity with Europe's major economic hubs. For this reason, high-speed rail (HSR) plays a central role in the planning of the Trans-European Transport Network (TEN-T), with Regulation (EU) 2024/1679, which defines the strategic corridors and priority projects that ensure balanced connectivity across Europe [12, 13].

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2027
O. Gervasi et al. (Eds.): ICCSA 2026 Workshops, LNCS 16763, pp. 556–569, 2027.
https://doi.org/10.1007/978-3-032-30530-5_35

1.1 Operational Models for HSR

The main factor that makes HSR infrastructure strategically important is the drastic reduction in travel times between the origins and destinations served. Indeed, travel time is considered the key factor determining competitiveness between high-speed rail and air for distances of up to around 1,000 km [14]. This competitiveness is closely linked to the type of operating model adopted. According to the classification by Campos and De Rus (2009), there are four operating models for rail services which define how the HSR service interacts with the existing infrastructure [15] (Fig. 1):

- Model 1 is characterised by separate infrastructures for high-speed and conventional trains and is known as the "Exclusive exploitation model";
- Model 2 refers to railway infrastructures where high-speed trains run on both dedicated lines and conventional sections, and is known as the "Mixed high-speed model";
- Model 3 provides for certain conventional trains to be able to use high-speed lines, this is known as the "Mixed conventional model";
- Model 4 allows conventional and high-speed trains to run on any infrastructure and is known as the "Fully mixed conventional model".

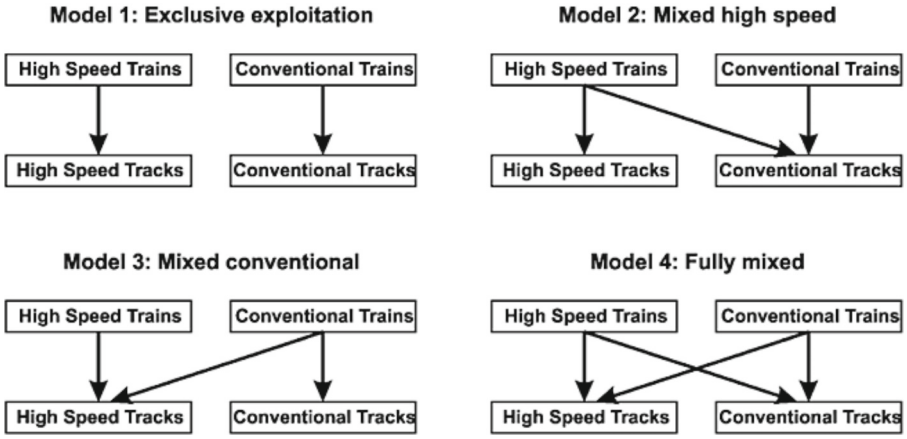


Fig. 1. HSR operational models [15].

Model 1 is the only dedicated service, whilst the other three belong to the mixed-service category. This distinction is significant because the competitiveness of the HSR service is reflected in the transition from mixed services to dedicated services, and thus to Model 1. Therefore, the dedicated lines generate the reduction in HSR train travel times which ensure the impacts on centrality and territorial attractiveness [16].

The improvement in the level of service associated with Model 1 (exclusive) has a direct effect on transport demand. According to the relevant scientific literature, there are specific time thresholds that influence user choices: for journeys with travel times of less than 2,5 h, the market is dominated by the HSR train; for travel times of more than

2,5 h and less than 3,5 h it is equally divided between the HSR train and air mode; for travel times of 3,5 to 5 h HSR still play a significant contribution; finally, above 5 h the air mode is dominant [14].

1.2 HSR Demand Analysis

As mentioned above, the analysis of travel demand is fundamental to understanding changes in passenger behaviour in relation to the transition from the various mixed operating Models (2, 3 and 4) to the exclusive operating Model 1. The travel demand generated by the introduction of a dedicated HSR line comprises three components that manifest themselves at different time intervals [17].

The first segment of demand consists of demand that shifts from other modes or transport services to the HSR network, known as diverted demand. This modal shift is determined by travel time and specific characteristics of the alternative modes, such as fares and the frequency of services offered. This component becomes apparent during operating time.

The second segment of demand relates to the new passenger flows, this is known as induced demand. The increase in demand is driven by the rise in the frequency of journeys made by the same users who were already travelling before the introduction of the dedicated HSR line and is linked to the significant reduction in travel times. The impact of this component on demand is a result of tactical choice.

The third segment of demand is demand driven by economic growth. This component is linked to new travel flows resulting from the economic and social impacts that the presence of the HSR line has on the region over time. In this case, the increase in demand is not directly linked to the improvement in service but is the result of structural changes in the territory. The impact of this component on demand occurs as a result of strategic outcomes.

The three components of demand can be estimated using Transport System Models (TSM) [18–21], in particular, mode/service choice models are used to estimate direct demand [22], while travel frequency models and destination choice models are used to estimate induced demand [23, 24], models capable of quantifying the relationships between economic development and mobility, known as SETI (Spatial Economic Transport Interaction), to estimate demand arising from economic growth [25, 26].

The application of these models depends on the availability of data. The scientific literature uses two types of surveys to analyse diverted and induced demand: Revealed Preference (RP) surveys, which reveal users' actual behaviour within the currently operating transport system, and Stated Preference (SP) surveys, which present realistic but non-operational infrastructure scenarios. In some situations, the RP approach can be replaced by the acquisition of datasets provided by agencies that monitor mobility flows.

1.3 LARG Paradigm

Analysing demand for HSR services therefore requires a methodological approach capable of describing users' choice behaviour and identifying the different segments of overall demand. To pursue this endpoint, the LARG paradigm provides a conceptual framework

for the development of new HSR lines that takes into account both strategic planning and technical design [2, 5, 8, 10, 11]. The LARG paradigm is based on four dimensions: *lean* dimension aims to reduce unnecessary costs without compromising service quality; *agile* dimension focuses on the infrastructure's capacity to respond to transport demand, estimating the three components of demand described above as factors determining service effectiveness; *resilient* dimension, which assesses the railway system's ability to respond to risk events such as safety and service regularity by restoring normal operating conditions; *green* dimension, which analyses the environmental sustainability of the infrastructure project by comparing energy consumption and pollutant emissions with other modes of transport, and in particular air mode.

This work falls within the LARG paradigm, focusing specifically on the *agile* dimension, which is dedicated to the study of demand, applying it to the Italian context, where the strategic role of extending HSR network has been identified as one of the priority challenges in the Piano Nazionale di Ripresa e Resilienza (PNRR) to reduce economic and infrastructural disparities between the northern and southern Italy [27].

This study aims to analyse the current modal split for travel between southern Italy and Rome, in both directions, with a particular focus on the Reggio Calabria–Rome relationship, which is currently served by a mixed rail service (operational Model 2). Hence, a methodological approach using mobility data derived from telephone datasets is adopted.

This study is useful to policy-makers and planners as it provides a methodological basis for analysing the impact of an HSR line on transport demand.

Following this introduction, the paper comprises Sect. 2, which explains the methodology for estimating demand; Sect. 3, which outlines the experimental study; and Sect. 4, which consists of the discussion and the final comments.

2 Methodology for Demand Estimation

2.1 Data Acquisitions

Estimating transport demand for high-speed services requires a dataset that reflects both users' actual choice behaviour within the current infrastructure context and their future behaviour, simulated by exploring infrastructure scenarios that have not yet been implemented. Thus, questionnaires are designed to investigate users' Revealed Preferences (RP) for the current situation and questionnaires designed to investigate users' Stated Preferences (SP) with regard to one or more hypothetical scenarios.

The questions contained in an RP questionnaire relate to a specific origin-destination (O-D) pair are designed to gather information on departure and arrival times, the reason for the journey, the mode of transport chosen for the journey, the frequency of the same journey, and any basic socio-economic information such as occupation, level of education, and the number of household members. As an integration to the RP questionnaire, data on specific origin-destination relationships can be obtained using nationwide mobility databases. These databases are provided by companies collecting mobility data and

storing information on observed passenger flows; they may include mode of travel, journey times, the average number of trips on O-D pairs for representative samples of travellers, and socio-economic information. The data contained in these databases, however, may be subject to anonymisation in accordance with current privacy regulations.

SP questionnaires describe one or more hypothetical scenarios relating to the construction of new infrastructure, which differ in terms of certain key attributes, such as fare levels and travel times for specific O-D pairs. The information gathered through this type of survey makes it possible to estimate changes in user behaviour following the introduction of transport options not yet available in the area. The SP questionnaire investigates two components of passenger demand: diverted demand and induced demand. In particular, the presentation of more than one hypothetical scenario to each respondent allows to collect a large number of observations.

Finally, RP data reflect actual behaviour, obtained from direct questionnaires or mobility databases; SP data, on the other hand, reflect users' simulated behaviour in relation to hypothetical scenarios, conditioned by the reliability of the responses, which may be influenced by the gap between the hypothetical scenarios and the real behaviour users will adopt in the future.

2.2 Models for Demand Estimation

Current and future demand is estimated using TSMs, which also include the models used to analyse supply and the interaction between supply and demand [19, 20, 22, 23, 28–35]. In academic literature, demand analysis refers to the four-stage model system, which breaks down the demand function into the product of subsets relating to different dimensions of choice [20]. The system consists of:

- emission model, which estimates the number of journeys generated by each origin;
- distribution model, which allocates journeys across different destinations;
- modal choice model, which allocates journeys across different modes of transport;
- path choice model, which defines the use of links in a transport network.

The design of one of these models involves three stages: specification of the functional form; calibration, which assigns values to the parameters based on the data collected from surveys; and validation through informal and statistical tests that verify the model's ability to reproduce reality.

The mathematical models found in the literature can be segmented into two categories, which differ according to the approach used.

The first category comprises models that employ a descriptive statistical approach. These models generate an aggregate estimation of travel demand, which is useful for large-scale analyses or preliminary studies.

The second category of models is based on discrete choice theory [36, 37] and includes models that adopt a probabilistic-behavioural approach to simulate users' choice behaviour. In these models the demand estimation is disaggregated, showing users' behaviour with respect to different variables.

Belonging to the second category are RUM (Random Utility Model) models, QUM (Quantum Utility Model) models and FUM (Fuzzy Utility Model) models [36–51]. RUM models are extensively explored in literature and are based on the assumption that the

user chooses the alternative that maximises utility. Utility consists of a deterministic component and a stochastic component that captures measurement errors. QUM and FUM models are recent extensions trying to overcome the limitations of RUM models.

This work has been carried out as part of the MOST Project – Spoke 4, which focuses on analysing both the demand for and supply of high-speed rail services [6, 22, 23, 30, 32, 33, 35, 52–55].

2.3 The Database Structure

The RP data has been acquired through the Vodafone Business Analytics service, which provides non-personal databases generated by the mobile network. The dataset is built in full compliance with privacy protection regulations, the information has been anonymised directly at source and disseminated only in aggregated form. The characteristics of the dataset used for this study are explained in Table 1.

Table 1. Summary of the dataset's features.

Features	Description
Modes of transport investigated	Air, train, bus
Minimum distance threshold for displacement detection	Only travel distances of more than 100 km
Number of travels	Aggregate count of travels by combination of attributes
Classification of passengers	Resident of origin, resident of destination, non-resident, foreign user

The "number of travels" information expresses the intensity of mobility flows based on spatial, temporal and modal characteristics. The "number of travels" is not referred to any individual user, but it is an aggregate count of all the journeys recorded during the observation period (35 days, from 15 March to 18 April 2025). Each trip corresponds to a complete sequence of movement that meets the methodological criteria defined by the project:

- True-Origin;
- Origin node (departure terminal);
- Destination node (arrival terminal);
- True-Destination.

The data is obtained by aggregating journeys that share the same combination of spatial (Table 2) and temporal (Table 3) attributes, for example: true-Origin, origin node, destination node, true-Destination, mode of travel, time slot of the journey, day of the week, passenger class. Therefore, this is not a direct count of passengers, but rather an aggregate number of journey that respects a minimum threshold of 15 users per journey. This measure allows to analyze passenger flows.

Table 2. Spatial attributes.

Attribute	Description	Specification
Origin node/ Destination node	Departure or arrival terminal (airport, railway station, hub)	10 airports 21 railway stations 19 bus hubs
True-Origin True-Destination	User's last stop (≥4 h) before departing from the origin infrastructure node User's first stop (≥4 h) after arriving at the destination infrastructure node	Calabria and Sicily: • Region • Province • Municipality Rome, Milan and Naples: • Region • Municipal district • Municipality
Geographical levels for defining travel Home-based	The user is a resident of the area in which the departure or arrival node is located	Region Province/Municipal district Municipality

Table 3. Temporal attributes.

Attribute	Description	Specification
Observation period	35 days from 15 March 2025 to 18 April 2025	Standard period: 15 March 2025 to 4 April 2025 Easter period: 5 April 2025 to 18 April 2025
Day of the week	Representative day on which mobility flow aggregates are measured	Monday, Tuesday, Wednesday, Thursday, Friday, Saturday, Sunday
Time slots (24 intervals)	One-hour interval during which the departure from the origin node is recorded	From 00:00–00:59 to 23:00–23:59
Macro-time slots (5 intervals)	Aggregation of time slots into 5 broader intervals	00:00–04:59 05:00–09:59 10:00–15:59 16:00–19:59 20:00–23:59

The data are derived from the population of mobile phone users affiliated with Vodafone company, which has been expanded using inference models to represent the entire traveller universe. The extrapolation process is based on calibration factors that include the distribution of market shares by geographical region and age group, the number of devices associated with each user, and mobile phone usage patterns. To ensure the reliability of the estimates, the model is constantly updated and validated through periodic

comparisons with data observed in known situations, such as sporting events, trade fairs or airports, thus enabling a high level of accuracy to be maintained.

3 Experimental Case Study

This paper focuses on analysing users' choice behaviour in relation to the introduction of a HSR line between Reggio Calabria and Salerno in southern Italy. Currently, the Italian rail network comprises 921 km of operational lines, located mainly in the north of the country [13, 56]. The transport options available for connecting the capital, Rome, with southern Italy include buses, cars, planes, conventional trains and a hybrid service that combines high-speed trains on dedicated lines from Rome to Salerno (operational model 1) and high-speed trains running on conventional lines from Salerno to Reggio Calabria (operational model 2) [57]. The experimental hypothesis behind the research is the implementation of a dedicated line for HSR services on the Salerno–Reggio Calabria section, with the aim of establishing a continuous high-speed service. The analysis of current demand is carried out using nationwide travel data obtained from a database. Future demand is analysed using data collected from a survey conducted at stations and airports in Sicily, Calabria and Rome.

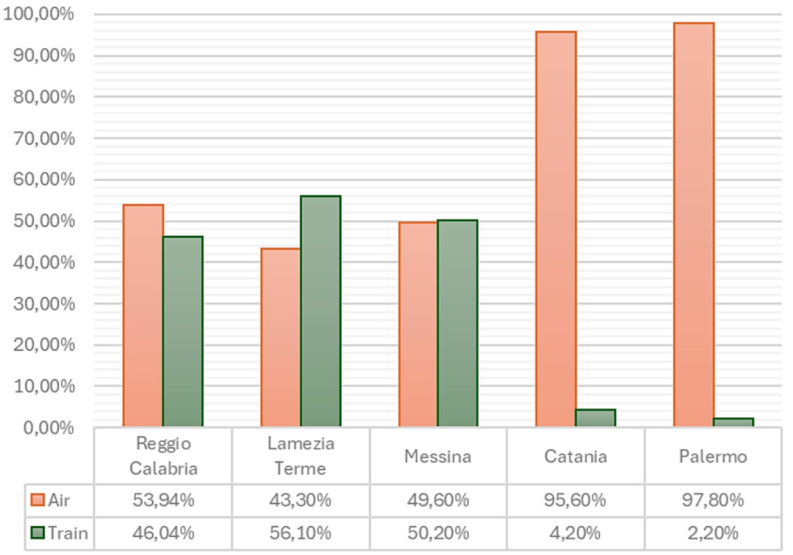
This paper takes an in-depth look at the methodology for collecting and analysing data relating to the current situation (RP).

To ensure privacy protection and statistical significance, the 'number of travels' is provided for aggregations containing at least 15 users. If a combination of attributes comprises fewer than 15 distinct users, the data is not released in its original form but is subject to a progressive masking procedure.

The following graphs show the modal split derived from RP data for travel to Rome (Fig. 2) from the Calabrian cities (Reggio Calabria and Lamezia Terme) and Sicilian cities (Messina, Catania and Palermo) covered by the study, and vice versa (Fig. 3), obtained in accordance with the graph shown as an illustrative example of travel choice between Calabria and Rome (Fig. 4).

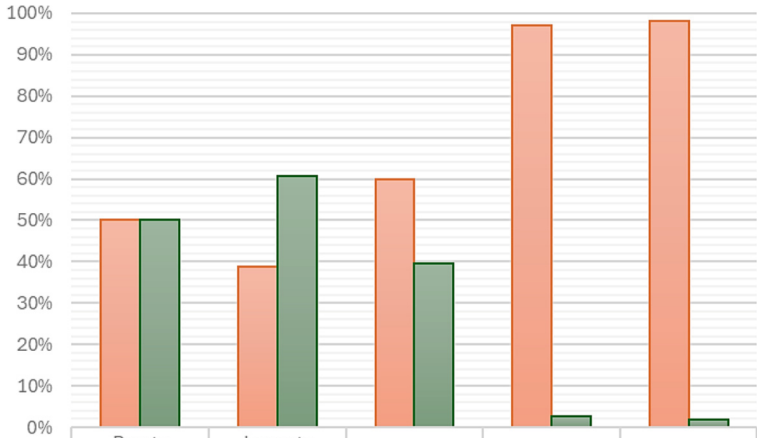
The data collected on the current situation (RP) provide a detailed overview of the modal split for travel between the main cities of Calabria and Sicily and Rome, in both directions. The analysis reveals a clear polarisation in transport choices, with air travel dominating for travel from Sicily.

The results obtained provide the basis for analysing current demand and for applying probabilistic-behavioural demand models specific to TSMs, with the aim of simulating user behaviour in relation to future scenarios concerning the introduction of a dedicated high-speed line.



	Reggio Calabria	Lamezia Terme	Messina	Catania	Palermo
Air	53,94%	43,30%	49,60%	95,60%	97,80%
Train	46,04%	56,10%	50,20%	4,20%	2,20%

Fig. 2. Modal split for travel from Calabria and Sicily to Rome.



	Reggio Calabria	Lamezia Terme	Messina	Catania	Palermo
Air	50%	38,80%	60%	97,20%	98,20%
Train	50%	60,80%	39,60%	2,60%	1,78%

Fig. 3. Modal split for travel from Rome to Calabria and Sicily.

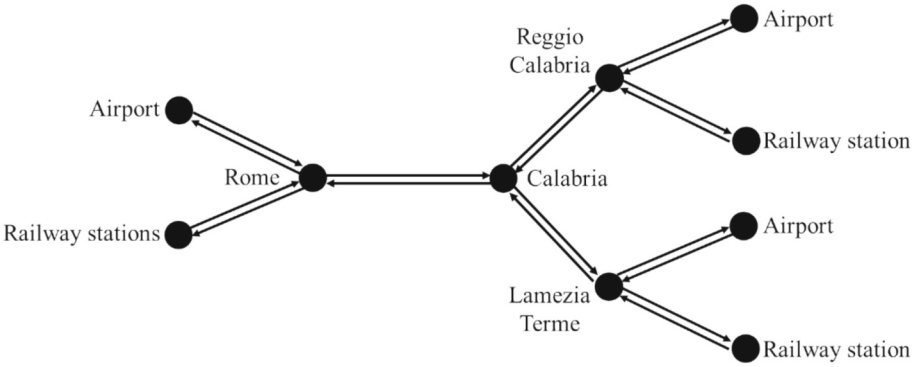


Fig. 4. Graph for the Calabria – Rome connection.

4 Conclusions

This research work falls within the LARG paradigm, focusing on the *agile* dimension dedicated to the study of demand. In order to apply demand models, data must be available. The literature identifies two types of surveys for analysing diverted and induced demand: Revealed Preference (RP) surveys and Stated Preference (SP) surveys. In some cases, the RP approach can be replaced by the acquisition of datasets provided by agencies that monitor mobility flows at national level.

This paper describes a dataset for the collection of RP data on a national scale in Italy. The dataset has been provided by Vodafone Business Analytics and has been constructed in accordance with the research project's guidelines. The database contains anonymised and aggregated data covering a 35-day observation period (15 March–18 April 2025), and includes information on 10 airport nodes, 21 railway nodes and 19 bus hubs, with a minimum distance threshold of 100 km for travel. True-Origin and True-Destination locations have been identified based on a stationary threshold of 4 consecutive hours, allowing the entire mobility chain to be reconstructed.

In contrast to studies based on traditional RP surveys, which are typically limited to small samples and information collected only at infrastructure nodes, this study uses a nationwide mobility dataset covering 35 consecutive days. Furthermore, the integration of "True-Origin" and "True-Destination" allows for the reconstruction of the entire mobility chain (access time, main journey, egress time), overcoming the common limitation of RP data limited to infrastructure nodes.

The preliminary analysis of data identified the current modal split for travels made from the cities of Reggio Calabria and Lamezia Terme, located in Calabria, and from Messina, Catania and Palermo, located in Sicily, to Rome and vice versa.

The results observed can be interpreted in light of discrete choice theory. According to RUM models, the probability of choosing a mode decreases as the associated disutility increases. Each of the attributes identified through the RP data has a specific theoretical expectation regarding its causal effect on mode choice. In particular, travel time, access time, and egress time are attributes of disutility, corresponding to a negative coefficient in the systematic utility function.

The RP data obtained from the dataset reveal patterns consistent with theoretical expectations. For example, the higher share of train travel from Lamezia Terme compared to Reggio Calabria is due to shorter travel time, which reduces the overall disutility of rail travel. Similar, the strong preference for air travel from Catania and Palermo is a result of the high disutility associated with rail travel and the time attribute. This evidence confirms the central role of travel time as a key factor, in line with the literature, on mode choice for medium- to long-distance travel.

These results are useful for studying current demand and for applying stochastic models belonging to the TSM class.

Future research plans to integrate SP data which, together with RP data, will enable the analysis of future transport demand generated by the introduction of a HSR line in a territory, particularly in southern Italy.

Acknowledgements. This study was carried out within the MOST – Sustainable Mobility National Research Center and received funding from the European Union Next-Generation EU (PIANO NAZIONALE DI RIPRESA E RESILIENZA (PNRR) – MISSIONE 4 COMPONENTE 2, INVESTIMENTO 1.4 – D.D. 1033 17/06/2022, CN00000023). This manuscript reflects only the authors' views and opinions, neither the European Union nor the European Commission can be considered responsible for them.

References

1. Santilli, G.: Italia divisa in due dalla Tav: Pil a +7% nelle città collegate (2020). https://www.ilsole24ore.com/art/italia-divisa-due-tav-pil-7percento-citta-collegate-ACCZKIFB
2. Russo, F.: Which high-speed rail? LARG approach between plan and design. Future Transp. **1**, 202–226 (2021). https://doi.org/10.3390/futuretransp1020013
3. European Commission: Sustainable and Smart Mobility Strategy – putting European transport on track for the future (2021). https://transport.ec.europa.eu/document/download/be22d311-4a07-4c29-8b72-d6d255846069_en?filename=2021-mobility-strategy-and-action-plan.pdf
4. Raicu, S., Costescu, D., Popa, M., Dragu, V.: Dynamic intercorrelations between transport/traffic infrastructures and territorial systems: from economic growth to sustainable development. Sustainability **13**, 11951 (2021). https://doi.org/10.3390/su132111951
5. He, S., Mei, L., Wang, L.: The dynamic influence of high-speed rail on the spatial structure of economic networks and the underlying mechanisms in Northeastern China. IJGI **10**, 776 (2021). https://doi.org/10.3390/ijgi10110776
6. Praticò, F.G., Fedele, R.: Economic sustainability of high-speed and high-capacity railways. Sustainability **15**, 725 (2022). https://doi.org/10.3390/su15010725
7. Ji, C., Yao, Y., Duan, J., Li, W.: Sustainable mechanism of the entrusted transportation management mode on high-speed rail and the impact of COVID-19: a case study of the Beijing-shanghai high-speed rail. Sustainability **14**, 1171 (2022). https://doi.org/10.3390/su14031171
8. Li, D., Jiang, R., Lu, Z., Sun, S., Wang, L.: Does the construction of high-speed rail change the development of regional finance? Sustainability **15**, 10641 (2023). https://doi.org/10.3390/su151310641
9. European Environment Agency: National emissions reported to the UNFCCC and to the EU Greenhouse Gas Monitoring Mechanism, April 2024 (2024). https://sdi.eea.europa.eu/catalogue/srv/api/records/6331f651-8863-4656-a911-669f2a332a1e?language=all. https://doi.org/10.2909/6331F651-8863-4656-A911-669F2A332A1E

10. Prakongwittaya, S., Liangrokapart, J.: Integrating LARG measures to improve supply chain transparency performance. Asia Pac. Manag. Rev. **30**, 100324 (2025). https://doi.org/10.1016/j.apmrv.2024.09.002
11. Surmařová, S., Neumannová, M., Pařil, V., Vrána, M., Chmelík, J.: Do I really like to shift to rail? Influence of rail modernisation on passenger preferences. Res. Transp. Bus. Manag. **59**, 101284 (2025). https://doi.org/10.1016/j.rtbm.2024.101284
12. European Union: Regulation (EU) No 1315/2013 of the European Parliament and of the Council (2013)
13. European Union: Regulation (EU) 2024/1679 of the European Parliament and of the Council (2024)
14. Givoni, M., Dobruszkes, F.: A review of ex-post evidence for mode substitution and induced demand following the introduction of high-speed rail. Transp. Rev. **33**, 720–742 (2013). https://doi.org/10.1080/01441647.2013.853707
15. Campos, J., De Rus, G.: Some stylized facts about high-speed rail: a review of HSR experiences around the world. Transp. Policy **16**, 19–28 (2009). https://doi.org/10.1016/j.tranpol.2009.02.008
16. Rindone, C., Russo, A.: Centrality analysis for railway network planning: constrained measures for high speed. Transp. Eng. **22**, 100393 (2025). https://doi.org/10.1016/j.treng.2025.100393
17. Ben-Akiva, M., Cascetta, E., Coppola, P., Papola, P., Velardi, V.: High speed rail demand forecasting in a competitive market: the Italian case study (2010)
18. Nuzzolo, A., Russo, F.: Departure time and path choice models for intercity transit assignment. Pergamon (1998)
19. Ortúzar, J.D.D., Willumsen, L.G.: Modelling Transport. Wiley (2011). https://doi.org/10.1002/9781119993308
20. Cascetta, E.: Transportation Systems Engineering: Theory and Methods. Springer, New York (2013)
21. Russo, F., Rindone, C.: Regional transport plans: from direction role denied to common rules identified. Sustainability **13**, 9052 (2021). https://doi.org/10.3390/su13169052
22. Russo, F., Sgro, D., Musolino, G.: Sustainable development of railway corridors: methods and models for high speed rail (HSR) demand analysis. In: Gervasi, O., et al. (eds.) ICCSA 2023. LNCS, vol. 14110, pp. 527–538. Springer, Cham (2023). https://doi.org/10.1007/978-3-031-37123-3_36
23. Russo, F., Moschella, M., Musolino, G.: Railway demand evaluation: hsr induced component. In: Gervasi, O., Murgante, B., Garau, C., Taniar, D., Rocha, A.M.A.C., Faginas Lago, M.N. (eds.) ICCSA 2024. LNCS, vol. 14822, pp. 173–187. Springer, Cham (2024). https://doi.org/10.1007/978-3-031-65318-6_12
24. Russo, F., Musolino, G., Moschella, M.: High-speed rail travel demand analysis: pilot experimentation on generation model. Transp. Res. Procedia **90**, 822–829 (2025). https://doi.org/10.1016/j.trpro.2025.06.074
25. Cascetta, E., Marzano, V., Papola, A.: Multi-regional input-output models for freight demand simulation at a national level. In: Ben-Akiva, M., Meersman, H., and Van De Voorde, E. (eds.) Recent Developments in Transport Modelling, pp. 93–116. Emerald Group Publishing Limited (2008). https://doi.org/10.1108/9781786359537-006
26. Russo, F., Musolino, G.: A unifying modelling framework to simulate the spatial economic transport interaction process at urban and national scales. J. Transp. Geogr. **24**, 189–197 (2012). https://doi.org/10.1016/j.jtrangeo.2012.02.003
27. CPI, Council Presidency of Italy: Piano Nazionale di Ripresa e Resilienza (PNRR) (2021). https://www.governo.it/sites/governo.it/files/PNRR_0.pdf

28. Russo, F., Rindone, C.: Container maritime transport on an international scale: data envelopment analysis for transhipment port. Presented at the Sustainable Development And Planning 2011 July 12 (2011). https://doi.org/10.2495/SDP110691
29. Russo, F., Musolino, G.: The role of emerging ICT in the ports: increasing utilities according to shared decisions. Front. Future Transp. **2**, 722812 (2021). https://doi.org/10.3389/ffutr.2021.722812
30. Di Gangi, M., Russo, F.: Potentiality of rail networks: integrated services on conventional and high-speed lines. Presented at the COMPRAIL, 2022 November 30 (2022). https://doi.org/10.2495/CR220091
31. Tesoriere, G., Russo, A., De Cet, G., Vianello, C., Campisi, T.: The centrality of Italian airports before and after the COVID-19 period: what happened? Eur. Transp. Trasporti Europei, 1–16 (2023). https://doi.org/10.48295/ET.2023.93.2
32. Russo, F., Sgro, D., Musolino, G.: Dynamic structure of fares for high speed rail services. In: Gervasi, O., Murgante, B., Garau, C., Taniar, D., C. Rocha, A.M.A., Faginas Lago, M.N. (eds.) ICCSA 2024. LNCS, vol. 14822, pp. 188–201. Springer, Cham (2024). https://doi.org/10.1007/978-3-031-65318-6_13
33. Rindone, C., Russo, A.: A network analysis for HSR services in the South of Italy. In: Gervasi, O., Murgante, B., Garau, C., Taniar, D., C. Rocha, A.M.A., Faginas Lago, M.N. (eds.) ICCSA 2024. LNCS, vol. 14822, pp. 217–232. Springer, Cham (2024). https://doi.org/10.1007/978-3-031-65318-6_15
34. Campisi, T., Russo, A., Trwdy, E., Zanne, M., Tesoriere, G.: Some considerations on the analysis of port centrality in the Adriatic basin for tourist transport purposes. Transp. Res. Procedia **83**, 125–132 (2025). https://doi.org/10.1016/j.trpro.2025.02.018
35. Moschella, M.: Domanda passeggeri High Speed Rail (HSR) in aree in ritardo di sviluppo: analisi sperimentale per la relazione Roma-Reggio Calabria. Presented at the Approfondimenti sulla mobilità terrestre (2025)
36. McFadden, D.: The measurement of urban travel demand. J. Public Econ. **3**, 303–328 (1974). https://doi.org/10.1016/0047-2727(74)90003-6
37. Ben-Akiva, M.E., Lerman, S.R.: Discrete Choice Analysis: Theory and Application to Travel Demand. MIT Press, Cambridge (1985)
38. Anderson, S.P., De Palma, A., Thisse, J.-F.: Discrete choice theory of product differentiation (1992). https://doi.org/10.7551/mitpress/2450.001.0001
39. Tversky, A., Shafir, E.: The disjunction effect in choice under uncertainty. Psychol. Sci. **3**, 305–309 (1992)
40. Russo, F.: Fuzzy theory in transportation field: fuzzy sets for simulating path choice behavior, pp. 279–283 (1997)
41. McFadden, D.: Disaggregate behavioral travel demand's RUM side - a 30-year retrospective (2001)
42. Cascetta, E., Papola, A.: Random utility models with implicit availability/perception of choice alternatives for the simulation of travel demand. Transp. Res. Part C Emerg. Technol. **9**, 249–263 (2001). https://doi.org/10.1016/S0968-090X(00)00036-X
43. Train, K.E.: Discrete Choice Methods with Simulation. Cambridge University Press, Cambridge (2009)
44. Quattrone, A., Vitetta, A.: Random and fuzzy utility models for road route choice. Transp. Res. Part E Logist. Transp. Rev. **47**, 1126–1139 (2011). https://doi.org/10.1016/j.tre.2011.04.007
45. Busemeyer, J.R., Bruza, P.D.: Quantum Models of Cognition and Decision. Cambridge University Press (2012). https://doi.org/10.1017/CBO9780511997716
46. Vitetta, A.: A quantum utility model for route choice in transport systems. Travel Behav. Soc. **3**, 29–37 (2016). https://doi.org/10.1016/j.tbs.2015.07.003

47. Tinessa, F., Papola, A., Marzano, V.: The importance of choosing appropriate random utility models in complex choice contexts. In: 2017 5th IEEE International Conference on Models and Technologies for Intelligent Transportation Systems (MT-ITS), Naples, Italy, pp. 884–888. IEEE (2017). https://doi.org/10.1109/MTITS.2017.8005638
48. Papola, A., Tinessa, F., Marzano, V.: Application of the combination of random utility models (CoRUM) to route choice. Transp. Res. Part B Methodol. **111**, 304–326 (2018). https://doi.org/10.1016/j.trb.2018.03.014
49. Ben-Akiva, M., McFadden, D., Train, K.: Foundations of stated preference elicitation: consumer behavior and choice-based conjoint analysis. FNT Econ. **10**, 1–144 (2019). https://doi.org/10.1561/0800000036
50. Croissant, Y.: Estimation of random utility models in R: the mlogit Package. J. Stat. Soft. **95** (2020). https://doi.org/10.18637/jss.v095.i11
51. Vitetta, A.: Advancing path choice in transport systems: insights from fuzzy logic models. Sustainability **18**, 3236 (2026). https://doi.org/10.3390/su18073236
52. Di Gangi, M., Russo, F.: Design of hybrid rail services on conventional and high-speed lines. IJTDI **7**, 113–121 (2023). https://doi.org/10.18280/ijtdi.070206
53. Giunta, M.: Trends and challenges in railway sustainability: the state of the art regarding measures, strategies, and assessment tools. Sustainability **15**, 16632 (2023). https://doi.org/10.3390/su152416632
54. Giunta, M., Leonardi, G.: Framework for life cycle railway sustainability assessment: a methodological approach based on advanced methods and tools. In: Gervasi, O., Murgante, B., Garau, C., Taniar, D., C. Rocha, A.M.A., Faginas Lago, M.N. (eds.) ICCSA 2024. LNCS, vol. 14822, pp. 233–244. Springer, Cham (2024). https://doi.org/10.1007/978-3-031-65318-6_16
55. Panuccio, P.: State of the art of sustainable development of railway nodes: the high speed rail stations in Italy. In: International Conference on Computational Science and Its Applications-ICCSA 2024 (2024, submitted to)
56. UIC: High-Speed Rail Atlas 4 Edition. International Union of Railways (UIC) - Paris 2023 (2023)
57. Russo, F., Moschella, M.: Mode choice at national level: revealed and stated preference survey for high-speed rail realization. In: Gervasi, O., et al. (eds.) ICCSA 2025. LNCS, vol. 15894, pp. 359–374. Springer, Cham (2026). https://doi.org/10.1007/978-3-031-97648-3_24