Mode Choice at National Level: Revealed and Stated Preference Survey for High-Speed Rail Realization

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Abstract. The high-speed rail (HSR) system is becoming increasingly important, on a world scale, for national travel. Some 130.000 km of lines are built in operation or under planning/construction. In the realization of new lines or in the improvement of existing ones to bring them up to a high-speed level it is increasingly important to study the passenger demand and therefore the distribution between the available modes. It is therefore necessary to provide accurate surveys that allow for immediately usable statistics or develop appropriate behavioral models.

Attention is therefore given to the way in which the structure of the survey to be carried out, which must contain both the acquisition of information of type Revealed Preference and of type Stated.

The result obtained is a first structure which has been subjected to a prototype sample. The survey has been tested in South of Italy, where is proposed the realisation of a HSR line.

Based on the results obtained with the prototype, the different sections are updated, in particular those relating to SP information for planned lines.

The interpretation of the result is particularly important because the structure established allows an ex-ante analysis of the questions to be asked by the respondents in relation to the specifications of the induced demand of the various levels to be obtained, and which are not available in literature because of their complexity.

The result is interesting for analysts, for planners and researchers because it defines a structure that can be used or appropriately modified in relation to the study to be carried out in a reality where HSR has to be built or where an upgrade of the conventional line to HSR is planned.

Keywords: mode choice · High Speed Rail (HSR) · Revealed Preference (RP) · Stated Preference (SP) · Survey · Demand analysis

1 Introduction

The environmental, social and economic benefits of high-speed rail (HSR) infrastructure are driving the opening of new lines around the world. In line with Agenda 2030 goals, HSR contributes to promote the energy efficiency and to afford the sustainability challenges by reducing environmental impact in terms of CO2 emissions [1, 2]. In addition

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to its environmental benefits, HSR transport plays a strategic role for the economic and social development, contributing to Gross Domestic Product (GDP) growth and economic competitiveness, and promoting social inclusion. For instance, HSR service is known to facilitate the access to job opportunities and essential services and to improve the connection between the most underdeveloped areas with the main centers [3–11].

The 9th Report on Economic, Social and Territorial Cohesion of the European Commission highlights how the improvement of transport networks is crucial for reducing territorial disparities within the European Union. In regions such as Southern Italy, Greece, Spain and Eastern Europe, per capita GDP is currently less than 75% of the EU average, and the lack of infrastructure is one of the main barriers to economic growth [12]. HSR has been recognized as one of the most important infrastructure solutions for reducing territorial inequalities, taking its place in the European TEN-T (Trans-European Transport Network) regulations [13, 14] that aim to distribute transport infrastructure across Europe through the planning of strategic corridors and priority projects. The significant reduction in travel times has led many states around the world to invest in HSR networks with the prospect of extending the current 59.000 km of lines with an additional 70.000 km [15]. However, the implementation of an HSR network brings up issues of social equity, as increased accessibility does not always mean a reduction in territorial inequalities.

Several studies analyzed the effects of HSR on social inclusion, highlighting the link between accessibility and distribution of economic benefits [16]. Accessibility is a key variable in the interaction between land use and transport and is defined as the ease with which people or goods can reach certain destinations [17]. While greater accessibility facilitates the connection between territories and increases economic growth, the experience of countries such as China and Spain has demonstrated that the implementation of HSR lines can also increase economic disparities between urban and rural areas [18–21]. Indeed, in cities directly served by HSR there is an increase in economic competitiveness, while areas excluded from HSR face demographic and social decline. In some contexts, HSR has accentuated the gap between the main urban centers and the peripheral ones worsening economic inequality [16].

This aspect emerges clearly in the Italian context where the economic gap between North and South is accentuated by differences in access to transport infrastructure [14, 22]. The presence of an under-dimensioned transport network in Southern Italy is one of the main constraints for the growth of these areas, limiting economic opportunities and attractiveness for investments and productive activities. The planning and implementation of an HSR network in the Southern Italy represents a strategic priority, as it allows the integration of these regions into national and international economic flows [4].

For the new infrastructure to generate the expected benefits, it is essential to conduct a transport demand analysis to predict its impact on mobility. Analyzing travel demand means estimating three components (Fig. 1) [23]:

- Diverted demand, which estimates the shift of users from other modes of transport or services to HSR. It is influenced by endogenous factors such as fares, frequency of service and, above all, travel time, which is the major factor in competitiveness between modes. As it involves a change in modal or service choice for existing users, mode-service models are used to estimate diverted demand using data collected

on Revealed Preferences (current situation) and Stated Preferences (assumed future situation);

- Induced demand, which estimates the increase in travel frequency on a given origin–destination pair or the change of final destination by the same users who travelled before the introduction of the high-speed service. It is closely linked to the improvement of spatial accessibility, made possible by an improvement in service levels such as increased speed, which results in a significant reduction in travel time. It leads to a net increase in mobility that may include additional travel for personal and professional reasons, which is why the induced demand is estimated with trip frequency and destination models based on stated user behaviour data with respect to a scenario not yet realised (SP);
- Economy growth demand, which estimates the new trips generated by the economic growth of the territory due to the introduction of the high-speed service. It is related to the interactions between transport and economic development and is not directly related to the improvement of transport services, but to the economic and social impacts generated over time by the presence of HSR. For this reason, it emerges in the long term as a result of structural changes in the territory and is estimated with Spatial Economic Transport Interaction (SETI) models.

In particular, induced demand represents an aspect which is still poorly investigated in the scientific literature but of crucial importance for assessing the medium- to long-term effects of HSR on passenger mobility [24].

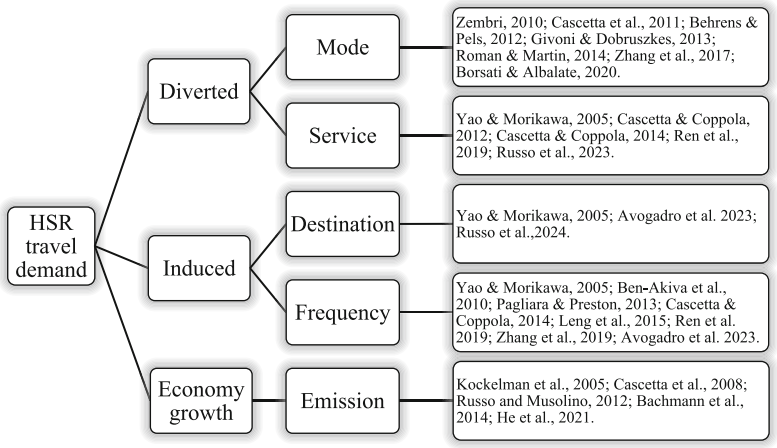


Fig. 1. HSR travel demand component.

Another key element in the study of demand concerns the evolution of HSR services. Four operational models exist according to [45] (Fig. 2), the 'exclusive exploitation' model where HSR and conventional trains have a separate infrastructure, the 'mixed high-speed' model where HSR trains run on dedicated sections and conventional lines, the 'mixed conventional' model where conventional trains run on dedicated sections and

high-speed lines, the 'fully mixed conventional' model where HSR and conventional trains run on both dedicated and non-dedicated sections.

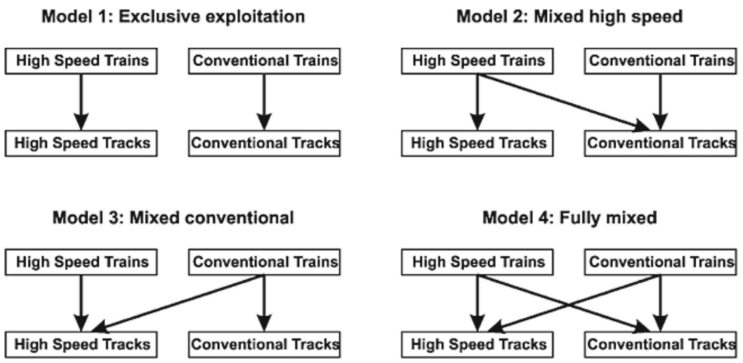


Fig. 2. HSR operational models [45].

Currently, many HSR networks operate in a mixed context, with high-speed trains running on both dedicated lines and conventional infrastructure (Model 2). The introduction of a new specially built HSR line, which is designed for speeds equal or higher than 250 km/h according to the EU 2016/797 European Directive [46], may change the demand structure by increasing the attractiveness of the service. The realization of the line leads to a decisive evolution of services from Model 2 to Model 1. This transition involves a drastic reduction in time distances for the same spatial distances. Furthermore, HSR becomes competitive with air transport up to distances of around 1000 km [28].

The methodological approach used to estimate transport demand involves collecting information on the travel behavior of users before the new infrastructure is built and on the behavior they would adopt after the infrastructure is built. To apply the methodology, the class of Revealed Preference (RP) surveys, which are useful for analyzing actual user behavior in the current transport system, are combined with Stated Preference (SP) surveys, which explore user choices in hypothetical but also realistic scenarios.

The objective of this paper is to provide a methodological structure for the realization of questionnaires on Revealed and Stated Preferences in order to collect the necessary data for applying both descriptive and behavioral Transport System Models (TSMs) [47, 48]. TSMs need general formulations [47, 48] and specific advancement for supply [49–51] and demand [24, 36, 52–54]. Hence, current and future travel demand can be estimated with particular reference to the diverted and induced demand components that emerge in the short and medium term respectively after the implementation of HSR lines.

This work is addressed to transport analysts and planners, as it provides the tools to carry out a survey that can be reproduced in any socio-economic context, and is structured as follows: Sect. 2 presents the description of the methodology for the design of a mixed RP/SP survey; Sect. 3 describes the experimental survey conducted in Southern Italy; Sect. 4 summarizes the objectives and results of the research.

2 Methodology for Survey Design

2.1 Travel Demand Models Considered in the Study

The methodology for analysing travel demand is based on the survey structures available in the literature and on various attributes considered important from a social, economic and modal point of view which are reported or not in the literature. Current and future demand can be estimated by applying models belonging to the class of TSMs, which also include models used to study supply and the interaction between supply and demand [47, 48]. The mathematical models in the literature belong to two categories that differ according to the approach used to forecast demand. Models based on statistical-descriptive approaches to analyze the relationships between socio-economic attributes and transport demand give an aggregate estimate of travel demand, useful for large-scale analyses. Whilst, models based on a probabilistic-behavioral approach to simulate user choices follow the discrete choice theory, generating a disaggregated demand estimate, which makes them suitable for the study of competition between different transport modes or services. Random utility models (RUM), fuzzy utility models (FUM) and quantum utility models (QUM) belong to this category [55–65]. The study presented in this paper takes place within the context of the MOST - spoke 4 project, which focuses on both demand [24, 36, 53, 54, 66, 67] and supply [7, 50, 52, 68–75] analysis of HSR services.

Data required for calibration of demand models are obtained from information on actual user choices in the current transport context and their decisions in hypothetical scenarios involving the introduction of new infrastructures. This information is gathered by conducting combined RP/SP surveys of representative samples of users of the transport system.

2.2 Revealed Preferences (RP) and Stated Preferences (SP) Survey

The RP and SP questionnaires must contain specific questions for investigating user behavior in relation to different alternative choices presented in different contexts. In RP questionnaires, respondents are asked to answer specific questions about their real journeys, such as origin and destination of the trip, the schedule, the mode of transport and the followed path. These data allow the calibration of demand models representative of actual user behavior (Table 1). On the other hand, SP questionnaires present to the respondents hypothetical scenarios with different variables, such as cost, travel time or frequency of a service. Such data allow to estimate how users will react to changes in the transport system, analyzing the impact of alternatives not yet available (Table 2). Moreover, SP surveys allow to investigate different components of induced demand, as well as the most common and widespread components of diverted demand.

Both types of surveys have advantages and disadvantages. RP provides fairly accurate information reflecting reality. However, they present a critical issue concerning the time and cost of conduction. With regards to SP surveys, a significant advantage is the possibility of collecting more information with the same cost and time, as each respondent is generally presented with several choice scenarios. However, these surveys are limited by the reliability of the answers, which may be influenced by the discrepancy between the hypothesized scenarios and the actual behavior of users in the future.

Table 1. Classification of information to be included in the RP questionnaire.

Data	Question	Purpose
Socio-economic	- Gender and age	Sample segmentation by demographic categories
	- Residence	Analyzing the relationship between travel choices and residence location
	- Education level	Assessing the influence of income on travel choices
	- Employment	Analyzing the relationship between travel choices and job profile
	- Economic indicators (n. of household members cars owned…)	Sample segmentation by expenditure potential categories
Travel habits	- Origin–Destination pair	Identify the different origins and destinations of travel to define flows
	- Trip purpose	Identify the main purposes of travel on the O-D pair
	- Frequency of travel	Quantifying existing demand
Current transport choices	- Transport mode	Identify the current modal split
	- Travel period	Analyzing the relationship between the transport choice and the period in which the travel occurs
	- Cost of travel	Assessing the economic and time impact on travel behavior
	- Factors influencing choice of transport mode (level of service, cost refund…)	Identify critical variables in the choice of transport

2.3 Modification of Attributes

As mentioned above, the scenarios presented in the SP questionnaire are characterized by different attribute values. Since each scenario represents a combination of relevant attributes, it is necessary to identify in advance the most significant attributes, the levels associated with each attribute, and whether the choice involves different transport modes (between modes) or different configurations of the same mode (within modes) [76–80]. The total number of possible combinations of attributes and levels can be extremely large. This number (N) can be determined through the Complete Factorial Plan (CFP)

Table 2. Classification of information to be included in the SP questionnaire

Data	Question	Purpose
Socio-economic	(Same questions as RP questionnaire)	Coherence between the two datasets for comparison
Hypothetical transport choice scenarios	- Availability of a new transport mode or service	Identifying the future modal split and estimating diverted demand
	- Different time travel and fares scenarios in comparison with current alternatives	Measuring the impact of main variables on future demand
Future behavior	- Increase in travel frequency	Estimating induced demand
	- Variations in overall journey length	Assessing the effect on travel choices
	- Willingness to change the travel purpose, residence, job location	Measuring the impact of changes in life opportunities (e.g. work)

which combines the number of attributes (n_i) and the number of levels of each attribute (m_i).

$$N = \prod_{i=1}^{k} m_i^{n_i} \tag{1}$$

The number of scenarios, i.e. the combination of attributes of interest, increases with increasing number of attributes and levels. In case of a large number of scenarios, factorialisation (Factorialisation Fractal Plan, FFP) and subdivision of the scenarios into several groups can be applied. Factorialisation eliminates some scenarios while maintaining the orthogonality of attributes variations between scenarios. The orthogonality represent the independence among the variations of attributes in different scenarios, which is an essential condition for isolating and correctly estimating the effect of each attribute on the choice [77]. Block splitting allows all scenarios to be split into groups, so that each individual respondent can answer a different set of questions with a limited number of scenarios submitted [48].

3 Experimental Survey

Following the above discussion, this chapter presents the survey designed to analyze user choice behavior in relation to real and hypothetical travel options after the introduction of an HSR line along the Reggio Calabria-Salerno route in Southern Italy. To achieve this aim, the questionnaire is designed by integrating RP and SP approaches. This dual perspective makes it possible to analyze current travel preferences and predict potential behavioral changes after the introduction of HSR.

In Italy, the HSR railway system includes 921 km of operational lines, with an additional 327 km under construction [14, 15]. For the connection between Southern

Italy and Rome, the available transport modes include car, bus, plane, conventional train and a hybrid service combining high-speed trains on dedicated lines from Salerno to Rome and traditional lines from Reggio Calabria to Salerno [11, 49–51].



Fig. 3. Core, Extended Core and Comprehensive Networks: Rail Passengers, airports [14].

Figure 3 illustrates the current status of the high-speed railway network in Southern Italy. The segment already completed from Rome to Battipaglia is shown in purple, while the one currently under construction, from Battipaglia to Praia, is shown in dashed purple. Finally, the segment analysed in this study, which extends from Praia to Reggio Calabria, is shown in green.

This survey focuses on the hypothesis of a railway infrastructure for HSR trains directly connecting Reggio Calabria to Salerno, creating a continuous service.

The questionnaire is divided into four main sections, each designed to collect specific information (Fig. 4).

The first part has two sections constructed following the RP methodology. The first section collects the socio-economic profile of the user through questions investigating variables such as gender, age, education level, employment status, residence and domicile, family composition and number of cars owned. The second section aims to gather

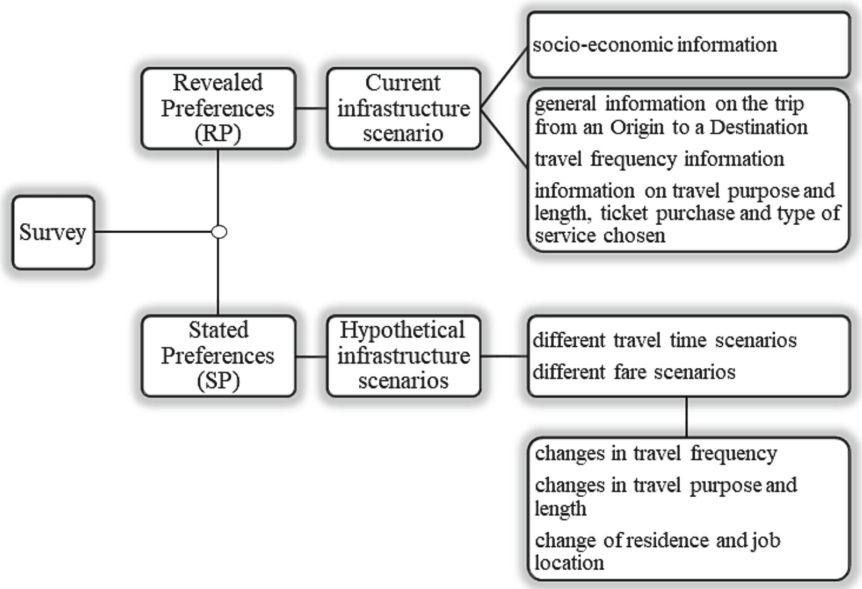


Fig. 4. Framework of the RP/SP survey.

information on the context in which the interview is conducted, including information on the place and date of the interview and the mode of transport being used. This section includes detailed questions about the current journey referring to travel purpose, travel frequency and length of stay at the destination. Both the two sections provide the basis for the analysis of current user behavior.

The second part of the survey is represented by the SP questionnaires. The Origin–Destination (O-D) pairs considered in the survey include connections between Rome and several cities in Southern Italy. The city of Rome (capital of Italy), represents the origin or destination of the trips. This part can be divided into two sections: the first one aims to estimate diverted demand and the second one the induced demand.

In order to estimate the diverted demand, two HSR train travel time scenarios with several fare scenarios are associated with each of the analyzed O-D pairs. The choice of the two travel times was determined on the basis of the meta-analysis of [28], which shows a direct correlation between travel time and preference for a specific transport mode. In addition, to investigate the market share of HSR, among the five alternatives available to connect the cities of southern Italy and Rome, a 10% and 20% increase in fares compared to current averages for air, conventional train and high-speed train modes is proposed to the interviewed users.

To realize the CFP explained in the previous chapter and compose the scenarios to be presented in the first part of the SP section, the fare attribute and three levels are chosen (current average fare, 10% and 20% increase). The FFP is applied to reduce the number of scenarios to be submitted to each respondent by eliminating the first-order interactions followed by the block splitting method. The final number of scenarios presented for each

O-D pair is thirty, subdivided into six groups, each comprising five fare scenarios that can be submitted to the individual user.

The second section of the SP questionnaire is dedicated to the estimation of induced demand and includes a series of questions to investigate the increase in frequency of trips for the same segment travelled in the RP part, the change in travel purpose and/or in length of stay at the destination, also possible new job and residence opportunities. Table 3 shows the results of the modal split of a pilot sample of users in the current situation for only one of the analyzed O-D pairs. These results derived from the data collected through the RP questionnaire (Table 1) with the aim of assessing the understanding of the questions and making some preliminary evaluations for testing the effectiveness of the methodology.

Table 3. Modal choice in current situation (RP)

Modal choice					
Socio-economic classification		Conventional train	Mixed HSR train	Air	Car
Gender	Male	22%	38%	24%	16%
	Female	18%	41%	18%	23%
Age	18–25	42%	28%	8%	22%
	26–45	-	60%	40%	-
	Over45	-	46%	35%	19%
Level of education	Graduate	38%	32%	8%	22%
	Master's degree	3%	46%	37%	14%
Employment status	Bachelor student	37%	32%	12%	19%
	Master's student				
	Ph.D student				
	Professor/Researcher	-	48%	36%	16%
	Employee				
Total		21%	39%	22%	18%

This prototypical survey has been useful for the construction of a survey including a larger and more significant number of participants interviewed at railway stations and airports in the selected cities to ensure adequate coverage of the target population. The interviewers follow a standardized protocol to ensure uniformity in data collection and consistency of responses. The questionnaires are divided according to the time scenarios presented in the SP sections and are only submitted to users travelling between the O-D pairs selected for the study. The data collected through the RP/SP survey are essential for the construction and calibration of descriptive and behavioral models, useful for estimating current and future demand for HSR services.

4 Conclusions

This study describes a methodology for building a survey to investigate the change in travel demand following the introduction of an HSR line in a territory. In order to study user behavior in the presence of modal alternatives not yet available, the survey collects RP information, relating to actual user behavior, and SP information, relating to scenarios not yet realized.

In particular, the survey investigates the impact on travel demand after the realization of a continuous HSR line between Reggio Calabria and Roma, which is currently served by a mixed system: HSR train with dedicated line from Salerno to Rome; HSR train with conventional line from Reggio Calabria to Salerno. The questionnaire is divided into two parts: the first one collects socio-economic information and details on the current journey (RP), the second one investigates preferences with respect to hypothetical future scenarios (SP). The purpose of the RP part is to study the actual behavior of users and to understand the factors influencing their transport choices in order to estimate the current travel demand. Whilst, the SP part aims to study user behavior in a future scenario in order to estimate diverted demand (shift from other modes or services to HSR) and induced demand (increase in travel frequency on the same O-D pair investigated in the RP). Two travel times are presented to the users of each selected O-D pair for the analysis of induced demand. For both of the travel times, thirty fare scenarios are generated, divided into six groups, obtained by increasing the value of the fares by 10% and 20% compared to current averages. Questions are asked to detect changes in travel frequency, travel length, travel purpose and job or residential opportunities.

Data collected can be used to develop aggregated and disaggregated forecast models belonging to the category of TSMs. These models are necessary to estimate future demand concerning HSR services, with particular regard to the induced demand component representing the net increase in travel on O-D fixed pairs, which is still poorly investigated in the existing literature.

Three types of future developments can be identified from the work performed. The first type concerns the implementation of the survey structure with a high sample size, verifying the goodness of the results already obtained. The second type concerns the possibility of calibrating diverted and induced models with different attribute structures. Finally, the third typology deals with the advancement of knowledge in the transition from full interview structures to reduced structures while maintaining orthogonality.

The methodology adopted makes it possible to analyze both the actual and the stated future behavior of users, to assess the impact of new infrastructures and to provide tools to support planning and decision-making in the transport sector. Thus, the integrated RP/SP approach allows a solid estimation of induced and diverted demand, which is crucial for the ex-ante evaluation of the effects of the realization of an HSR line in underdeveloped areas, such as Southern Italy.

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This manuscript reflects only the authors' views and opinions, neither the European Union nor the European Commission can be considered responsible for them.

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