Railway Demand Evaluation: HSR Induced Component

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Abstract. The introduction of High-Speed Rail (HSR) systems in different countries of the world has demonstrated to be a decisive solution for the sustainable development of the mobility and economic growth, and for the promotion of social inclusion. This paper aims to identify the main methodological approaches to evaluate travel demand induced by the presence of HSR services through a systematic review of the relevant scientific literature. The objective is the exploration of the proposed models and methodological gaps present in the existing research. The findings of this study provide a solid basis for future development in the study of induced demand generated by HSR services, suggesting necessary directions for the advancement of demand analysis methodologies, thus contributing to a more comprehensive analysis of the effects of high-speed rail systems.

Keyword: High-Speed Rail · HSR · passenger demand models · induced demand

1 Introduction

High-Speed Rail (HSR) transportation has gradually gained importance in the land global transport, emerging as a decisive solution to address mobility challenges in the 21st century. The technical definition of HSR varies from country to country. According to European Directive EU 2016/797 of the European Parliament and of the Council of 11 May 2016, within Annex I, the reference parameters for defining HSR railway lines [1] are: high-speed lines designed for speeds equal to or greater than 250 km/h; high-speed lines suitable for a speed of the order of 200 km/h; high-speed lines enhanced, which have special characteristics due to territorial contexts (of importance or urban planning), for which the speed varies according to the specificities of the place. In line with European legislation, the 2018 UIC (Union Internationale des Chemins de Fer) Directive established the commercial speed of 250 km/h as the main criterion for defining HSR [2]. The European Rail Infrastructure Managers in 2008 proposed a classification of railway lines according to demand segments and infrastructure characteristics, also proposing a network vision for 2035 [3]. In the case of high-speed trains, a maximum speed of 360 km/h by 2035 was envisaged.

The continuous evolution of HSR network planning offers opportunities for an increasingly efficient and extended rail service, which makes full use of both new high-speed infrastructure and existing conventional lines. This approach maximises the use of

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existing infrastructure, improving the efficiency and accessibility of the railway system as a whole. During the development of new lines, from the strategic planning phase to the executive design phase, it is essential to have a clear vision of the services that can be activated on the planned HSR lines and on the existing conventional railway lines [4]. The problem of operating models in the presence of HSR and conventional network was analysed in [5], which schematized four operating models:

– "Exclusive exploitation model": characterized by the clear division between HSR and conventional rail service, both with their own infrastructure (model adopted by Shinkansen technology in Japan);
– "Mixed high-speed model": HSR trains run on new dedicated infrastructure or on conventional sections of line (model adopted by France and Italy);
– "Mixed conventional model": some conventional trains run on HSR lines (model adopted in Spain);
– "Fully mixed conventional model": allows maximum flexibility, that is both HSR trains and conventional trains can travel on any type of infrastructure (Fig. 1).

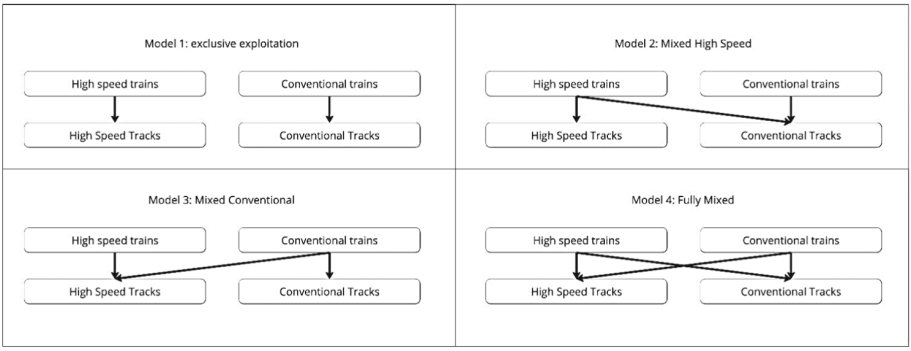


Fig. 1. Operational models for high-speed rail traffic [5].

The growth of HSR lines over the years has influenced the travel behaviour of users, leading to social, economic and environmental changes in the areas covered by the service. In fact, the reduction in journey times and the progressive increase in the frequency of HSR services compared to traditional services have determined effects that can be classified as internal and external in relation to socio-economic characteristics and transport services. Internal impacts concern the transport system, expressed in terms of level of demand, modal share and changes in transport accessibility. External impacts concern both the socio-economic, which also includes land use, as well as the environmental elements [6]. Among the socio-economic ones, the issue of social inclusion is closely linked to that of accessibility to services. The measure of accessibility is often used as an indicator of spatial equity because it reflects the ease with which people can reach specific destinations from a specific origin [7]. A high level of accessibility is crucial for improving the quality of life in cities because, with increased connections, people can carry out their activities at a lower cost (in terms of both money and time) [8].

HSR has effectively established itself as a new mode of transport, emerging as a new alternative to aircraft and conventional train. The reasons for this growing importance are related to environmental sustainability, operational efficiency, economic development, sustainable mobility and integration between the connected regions. Indeed, HSR is the most sustainable transport option compared to other modes such as aviation and cars for specific class of distances.

These features make HSR transport a decisive option for addressing climate change challenges. Increasing the share of passengers and freight transported by rail is a relevant key to achieving the 'zero emissions' targets of Goal 13 of Agenda 2030 [9]. The crucial element of the relevance of HSR is the significant reduction in travel times. The average speed of HSR services makes it possible to connect cities significantly faster than other means of transport (when the cities are far below a distance threshold), promoting greater connectivity between regions. The connection could also be estimated by means of the concept of centrality, in all its specifications, to verify the quality of the infrastructural networks and services [10, 11]. This not only improves mobility, but also stimulates economic development through increased accessibility to services and greater connectivity of industrial agglomerations with the distribution network. As a matter of fact, some studies [12–15] estimated the benefits in the case of a commercial port in connection with a Special Economic Zone (SEZ).

The realisation of HSR has impacts on the increase of GDP (Gross Domestic Product), in fact, economic benefits derive from the introduction of this service both in the short term, e.g. for the realisation of the projects themselves, and in the long term, due to employment growth through commercial, residential and industrial development along the HSR lines, which would also act as a driving force for tourist attractiveness [16]. In this sense, the implementation of the HSR network is an effective direction to the economic and social development problems of under-developed regions both in terms of competitiveness and connectivity. For example, the presence of HSR could produce in the cities of Southern Italy, a differential increase of 7 percentage points of GDP within 10 years [17].

The estimation of the impact of HSR on demand is crucial for the effective planning of new HSR lines, considering the expected social benefits of greater accessibility between connected cities, the economic benefits of increased mobility of people and goods and the environmental implications of reducing greenhouse gases compared to other modes of transport.

The estimation of new demand caused by the presence of HSR is therefore the main challenge in assessing how HSR influence sustainable development. In this sense, the phenomenon of induced demand is not limited to new passengers who would not have travelled without the HSR, but also includes those who, coming from other modes of transport or traditional rail services, increase the frequency of their travel due to the increased benefit of the HSR.

Although there are numerous studies in the literature investigating the competition of HSR with other transport modes, there are few works estimating the impact of HSR on long-term demand, which does not consider modal substitution but the net increase in demand generated by the presence of HSR. The aim of this paper is to identify the key

issues of the induced demand component, in order to provide a useful basis for additional investigations and analyses in the research topic of HSR-induced demand.

The research activity presented in this article is in line with other studies that deal with the impacts of HSR services. Rindone and Russo [18] performed a network analysis considering the existing HSR services in Southern Italy. Russo et al. [19] deal with an analysis of the dynamic structure a fares of HSR services in Italy. Panuccio [20] proposes a state-of-the-art on the sustainable development of railway nodes, with specific reference to the new HSR stations in Italy.

After this introduction, the paper is divided into four sections: Sect. 2 recalls the three demand components related to HSR; Sect. 3 reviews the literature concerning induced demand; Sect. 4 classifies the variables used by the authors to estimate induced demand; the last section is devoted to the conclusions derived from the review of the literature.

2 HSR Travel Demand Models

The introduction of HSR in several regions of the world has attracted considerable economic, social and environmental interest. In general, the presence of HSR generates three different components of travel demand [21]:

- Diverted demand;
- Induced demand;
- Economic growth demand.

Diverted demand refers to demand already present but diverted from other modes to HSR, therefore demand already present in car, bus, aeroplane, or other conventional rail services (intercity). The attributes influencing this type of demand are endogenous to the transport system, such as on-board travel time, ticket price, frequency of service, location and number of railway stations, but also the location of airports. Moreover, as shown by Givoni and Dobruszkes [22], demand diverted from other modes to HSR would present variations in relation to travel time. In particular, with regard to the impact of HSR on traffic by air mode, the study showed that: for travel times less than 2.5 h the choice of HSR is dominant, for travel times of around 3.5 h users' choices are equally distributed between HSR and aeroplane, while for travel times of more than 5 h users predominantly choose aeroplane.

The growth of HSR demand is a result not only of the modal diversion to HSR but also of HSR induced demand. According to Cascetta and Coppola [23], induced demand is classified into: direct, when changes in travel frequency occur; indirect, when it relates to an increase in mobility caused by changes in travellers' mobility choices or lifestyles.

Demand due to economic growth is influenced by national and international economic trends, considering that higher income leads to greater travel demand and vice versa. Russo et al. [24] classify the three HSR demand segments based on the choice dimensions schematised with partial-share demand models.

The travel demand is therefore influenced by the socio-economic characteristics of the users, the existing transport system and economic attributes, and the territory. According to the basic assumptions on which they are based, demand models can be classified into Statistical-Descriptive and Probabilistic-Behavioural models [25–27]. Descriptive

models focus on observed relationships between socio-economic variables, service levels and demand flows (or percentages); behavioural models derive from explicit assumptions about user behaviour and attempt to interpret it through probabilistic functions. In behavioural models, the choice of the alternative belonging to the set of choices perceived by the user is normally described by means of random utility models (RUM) [25–27], fuzzy utility models (FUM) [28–30] and quantum utility models (QUM) [31, 32]. The calibration of the models is approached in aggregated or disaggregated form. In the first case, aggregated and indirect information on user behaviour is used, typically data sets obtained from ticket sales or passenger flow counts, or from national statistics. Disaggregated models simulate the choice process of the individual decision-maker (user) and are classified into mono-modal, to analyse the effect of technological changes on a specific transport mode, and multi-modal, designed to simulate competition between HSR and other modes and/or rail services [23]. The disaggregated estimation of demand patterns is conducted through surveys that provide elementary information on the mobility behaviour of a sample of users. These surveys belong to two classes: surveys that reveal or demonstrate the current user behaviour in a real context are called Revealed Preference (RP); surveys concerning declared user behaviour in a hypothetical context are called Stated Preferences (SP) [27].

The three HSR demand components defined above are associated with one or more partial share models, which simulate one or more dimensions of trip [24]. Specifically, diverted demand can be estimated with mode-service-company-run choice models, while induced demand, both direct and indirect, can be estimated using trip generation and trip destination models. Travel demand generated by economic growth can be estimated as the result of the application of Spatial Economic Transport Interaction (SETI) models, simulating a transport-economy system [33].

3 Literature Review of Induced Demand

In the context of the planning and implementation of HSR services, the comprehension and the analysis of induced demand plays a fundamental role. This demand component emerges temporally following the diverted demand and prior to economic growth demand and turns out to be extremely important because it supports the increase in demand after the HSR has been opened. Accessibility has a key role in increasing demand, as the locational advantages provided by the expansion of HSR allow citizens living in the closest cities to travel more frequently and change destinations. However, the induced demand has been little investigated in the literature due to its complexity.

This section presents a review of the literature in order to analyze and synthesize the state of the art concerning the induced demand models proposed, with the aim of identifying the gaps in the evaluation of the percentage of induced demand generated by the presence of HSR.

In order to conduct an accurate analysis, some keyword search criteria were developed as a methodological basis for critically examining elements of the various papers and assessing their relevance to the topic.

A few papers were selected in which the topic of induced demand was addressed. The selected papers were analysed according to six categories (Table 1).

- Partial share (Generation or Distribution): simulated choice dimension.
- Country (C): differences between national contexts regarding the various elements of transport on a national scale (infrastructure, socio-economic context, etc.).
- Approach: proposed model for estimation of induced demand (Statistical-Descriptive or Probabilistic-Behavioural).
- Specification (S): presence of formal specification of the model.
- Calibration/Validation (C/V): description of the method and the reference set of data used for the model calibration and validation.
- Parameters (P): presence of the calibrated parameters.

Table 1. Classification of the literature about HSR induced demand.

Authors	C	Generation					Distribution				
		Approach		S	C/V	P	Approach		S	C/V	P
		S-D	P-B				S-D	P-B			
Yao & Morikawa (2005) [34]	J	x			x	Y		x		x	Y
Ben-Akiva et al. (2010) [21]	I	x			x	N					
Pagliara & Preston (2013) [35]	E	x		L-R	x	Y					
Cascetta & Coppola (2014) [23]	I		x	Logit	x	Y					
Leng et al. (2015) [36]	C	x		L-R		N					
Ren et al. (2019) [37]	C	x		L-R	x	Y					
Zhang et al. (2019) [38]	U		x	B-R	x	Y					
Avogadro et al. (2023) [39]	H	x		L-R	x	Y	x			x	Y

C = Country, S = Specification, C/V = Calibration/Validation, P = Parameters, J = Japan, I = Italy, E = England, C = China, U = USA, H = Holland.

The aim of this work is to provide a comprehensive review of the research about the induced demand by highlighting the progress in this topic over the last twenty years.

The main elements of the literature's review of induced demand have been focused through this classification. Table 1 summarizes the results obtained from the examination of each publication according to the defined criteria.

In a case study carried out in Japan, Yao and Morikawa [34] proposed an integrated model of intercity travel demand with a nested structure consisting of the following sub-models: route choice, mode choice, destination choice and travel choice. The authors' goal is to make the model sensitive to changes in travel conditions so that possible induced trips can be estimated. The authors calibrated the generation and distribution models. The distribution model, estimated through disaggregated data, is of the Logit type. The specification of the utility of destination choice includes variables accounting for the level of service and specific characteristics of the cities reached by the HSR service, and the explanatory variable (logsum) derived from the mode/route choice model. The authors did not report the specification of the model. The generation model was calibrated using a Statistical-Descriptive approach, where the attributes considered are: the accessibility for a person in the origin area multiplied by the population and the working population in the service sector. Accessibility is the logsum that measures the effects of mode/route and destination choices. The data used for the study came from RP-SP surveys and aggregate data. The authors estimated the generation model as an aggregate model. By measuring accessibility, the generation model becomes sensitive to variations in travel conditions, allowing the authors to estimate the elasticity of demand.

In the study of Ben-Akiva et al. [21], the induced demand model was defined as: "*the model which estimates the additional HSR demand due to the improvement of HSR level of services*". According to the results, the basis of the induced demand model is the relationship between current demand for HSR services, which is the dependent variable of the model, and independent variables such as current travel times and costs of HSR services, as well as the socio-economic variables of the population of the areas reached by HSR services.

In the study by Pagliara and Preston [35], induced demand is investigated by applying a gravitational model, with the aim of predicting the changes in the number of trips before and after the introduction of HSR services in Great Britain. The data used were provided by the Office of Rail Regulation (ORR) and represent the total number of trips made annually in the British railway stations. The study considers several origins and London as the only destination. The number of trips from station i is denoted by T_i and is given by:

$$lnT_i = \beta_0 + \beta_1 lnCP_i + \beta_2 ln\left(\sum\nolimits_{HSR} exp\left(U_{ij}\right)\right)_i + \beta_3 \ln(HSR)_i + \beta_4 \ln(districtHub)_i \quad (1)$$

where β_0 is the intercept, CP_i is the number of car parking areas available in the station i, *HSR* is a dummy variable that has value 1 for the station covered by the HSR service only and value 0 otherwise, *districtHub* is a dummy variable that has value 1 if the station is central to the district area and 0 otherwise. Finally, the logsum was calculated considering the travel time and fare for each station to London.

Cascetta and Coppola [23], in order to estimate the increase in HSR induced demand levels in Italy, calibrated travel frequency models belonging to the class of behavioural

models. The aim was to obtain the probability that, for a specific purpose and time period, a transport user makes a certain number of trips. The proposed trip-frequency model is as follows:

$$d_o[h] = \sum_i \sum_s n^i[o] m^i[osh] \tag{2}$$

where i is the generic user, o is the origin, h is the reference period, s is the travel purpose, $n^i[o]$ is the number of users belonging to class i present into the origin and $m^i[osh]$ is the number of trips made by the generic user equal to:

$$m^i[osh] = \sum_x \sum_d x p^i[x/odsh] \tag{3}$$

In Eq. (3), $p^i[x/odsh]$ is the probability that a generic user makes x trips, for purpose s and in period h, on the specific OD pair ("OD-based models"), obtained through a logit model:

$$p^i[x/odsh] = \frac{exp\left[V^i(x/odsh)\right]}{\sum_{x'=0,1,2+} exp\left[V^i(x\prime/odsh)\right]} \tag{4}$$

The authors chose as a reference period a winter period in which people travel to mountain destinations (the so-called "ski week") and two travel purposes ("business" and "non-business"). The choice set consists of the alternatives "no trip", "one trip per week" and "more than one trip per week" between origins and destinations represented by Italian administrative areas, called "province". They obtained the average number of trips made by each user as the weighted average of the number of trips x corresponding to frequency classes "0″,."1″ and "2 +", assigning weights to the probability of choosing each frequency class. The systematic utilities consider socioeconomic attributes (gender, professional status, level of degree) and variables associated with the level of service for the OD pair.

$$V(x = 0) = ASC_0 \tag{5}$$

$$\begin{aligned} V(x = 1) &= \beta_{ADD1} Add_{res}(o) + \beta_{male1} male + \beta_{degree1} degree \\ &+ \beta_{occ_{high1}} Occ_{high} + \beta_{logsum2} Logsum(o, d) + \beta_{sogliaT_{min120_1}} sogliaT120(o, d) \\ &+ ASC_1 \end{aligned} \tag{6}$$

$$\begin{aligned} V(x = 2+) &= \beta_{ADD2} Add_{res}(o) + \beta_{male2} male + \beta_{degree2} degree + \\ &\beta_{occ_{high2}} Occ_{high} + \beta_{logsum2} Logsum(o, d) + \beta_{sogliaT_{min120_2}} sogliaT120(o, d) \end{aligned} \tag{7}$$

with $Add_{res}(o)$, total employment in the province of residence "o", $Logsum(o, d)$ inclusive variable that depends on the level of service of the modes available in the OD pair, Occ_{high}, dummy variable that is equal to 1 if the user has a high professional status, $sogliaT120(o, d)$, dummy variable that is equal to 1 if the travel time on the OD pair is less than 120 min. The parameters were calibrated using the Maximum Likelihood method. Model estimates show a non-linear trend in the trip-frequency. In particular,

there is a significant increase in mobility below the minimum threshold of 120 min to travel between the OD pair.

Leng et al. [36] dealt with passenger flow forecasting for the entire Chinese HSR rail network, using trip generation forecasting as a reference. The induced demand flow is estimated for each O-D pair:

$$I_{OD} = I_{OD} \frac{TI}{\sum_{O=1}^{N} \sum_{D=1}^{N} I_{OD}} = I_{OD} \frac{T - TG - TD}{\sum_{O=1}^{N} \sum_{D=1}^{N} I_{OD}} \tag{8}$$

The authors indicate with I_{OD} the induced demand for the O-D pair. TI is the total induced demand which is equal to the total passenger demand (T) from which total economy-based demand (TG) and total diverted demand (TD) are subtracted. The estimated values are calculated by comparing the demand flows observed in 2008 with the demand flows observed in 2011.

The results of the study by Ren et al. [37] carried out on the 307 km Chengdu-Chongqing corridor show that the opening of an HSR line leads to a substantial increase in travel frequency not only for users travelling for personal reasons but also for commuters travelling for work. The model proposed by the authors is an Ordered Probit model specified as follows:

$$Y_i = \beta X_i + \varepsilon_i \tag{9}$$

where the dependent variable Y_i was measured by the variations in travel frequencies observed before and after the opening of HSR. The values of calibrated parameters are reported in the study. The authors also proposed an index to measure the change in the economic link between Chengdu and Chongqing:

$$R_{ij} = (\sqrt{P_i G_i} \times \sqrt{P_j G_j}) / D_{ij}^2 \tag{10}$$

where, i and j are the regions, P is the population, G is the GDP and D_{ij}^2 is shortest travel time by HSR between the two cities.

In the study conducted by Zhang et al. [38], a modelling framework is proposed for analysing induced travel demand in the context of a new transport mode in the Dallas-San Antonio corridor in Texas. Data were collected by an online survey that included questions on socio-economic factors, previous travel experiences, and hypothetical parameters of the new mode. Respondents included travellers on the corridor and residents in the study area. Each respondent answered eight questions on the frequency of their trips corresponding to different scenario configurations concerning the new HSR service. The data were analysed using econometric models. The authors selected a negative binomial panel-data model:

$$P = \frac{\Gamma(\lambda_{it} + y_{it})}{\Gamma(\lambda_{it})\Gamma(y_{it} + 1)} \left(\frac{1}{1 + \delta_i}\right)^{\lambda_{it}} \left(\frac{\delta_i}{1 + \delta_i}\right)^{y_{it}} \tag{11}$$

where y_{it} is number of stated additional trips for the t-th observation of the i-th respondent; Γ is a gamma distribution; δ_i is the dispersion parameter; $\lambda_{it} = \exp(X_{it}\beta)$; X_{it} is the

independent variables; β is the coefficient to be estimated. In addition, the authors quantified the induced travel demand ratio as:

$$Induced\ Demand\ Ratio = \frac{Induced\ travel\ demand}{Current\ Travel\ Market\ Size} \tag{12}$$

An important element introduced in the paper of Zhang et al. [38] is the possibility of calculating the induced demand in relation to all combinations of travel time and cost. The authors showed how induced demand is sensitive to the variation of these parameters.

Avogadro et al. [39] discussed various policy measures and their impact on modal choice between air and HSR markets between Amsterdam and London. The authors specified two aggregate models for a specific OD pair using a Statistical-Descriptive approach: distribution model and generation model. The data used for the study was provided by the International Passenger Survey (IPS), an aggregated database that provides information on the number and types of passengers entering and leaving the United Kingdom. The authors estimated the distribution model by regressing the difference between the modal share (air vs. HSR) according to the differences between the attributes. The generation model is specified as follows:

$$Q_{mt} = D_{mt} Los_{mt}^{\theta} = \exp(K_{mt}) Pop_{mt}^{\rho} GDP_{mt}^{\tau} Logsum_{mt}^{\theta} \tag{13}$$

where the potential demand on a specific OD pair, D_{mt}, is a function of population, *Pop*, and GDP per-capita, *GDP*; *m* is the sub-market (OD pair), *t* is the reference period, K_{mt} is a sub-market-specific constant and $Logsum_{mt}^{\theta}$ is the inclusive utility which measures the aggregate utility provided by the travel alternatives:

$$V_{i,mt} = \alpha_i + \beta \ln\left(freq_{i,mt}\right) + \beta traveltime_{i,mt} + \beta travelcost_{i,mt} + \beta HSR \times ln(freq_{i,mt}) \tag{14}$$

where *i* is the air/train modal alternative, $freq_{i,mt}$ is the frequency of the alternative *i* in sub-market *m*, $HSRln(freq_{i,mt})$ is an interaction term between frequency and HSR mode, $traveltime_{i,mt}$ is the travel time for the alternative *i* and $travelcost_{i,mt}$ is the fare for the trip alternative *i*. The models were both calibrated.

4 Discussion

The studies analysed in this paper represent the most significant advances in current knowledge regarding the estimation of induced demand generated by the presence of HSR. Five of these studies contain the calibrated parameters [23, 34, 37–39], reported in Tables 2 and 3.

The tables classify the variables used by the authors to estimate generation demand (Table 2) and distribution demand (Table 3). The proposed classes concern the territory's economy, the users' socio-economic condition, the level of service and the travel purposes. The variables may have different structures: Boolean (B) variables, Continuous (C) variables and Discrete (D) variables.

Table 2. Classification of variables used to estimate generation demand.

Class	Variable	[34]		[23]		[37]	[38]	[39]	
		B	NB	B	NB			B	NB
Territorial economy	GDP							B	B
	Employment			C	C				
	Population							B	B
	Work.pop.s.s.	C							
User Socio economic	Gender			B	B	B			
	Age					D	B		
	Education					D			
	Graduation			B	B				
	Professional s.			B	B				
	Career					D			
	Salary					D	C		
	Dist. Home						C		
	Vehicle/s						B		
LoS	Time			B	B	B	C		
	Tariff					B	C		
	Amenity					B			
	Punctuality					B			
	Safety					B			
	Frequency						C		
	Refund						B		
Logsum	Mode-choice			C	C			C	C
	LoS							C	C
	Access*pop.	C	C						
Purpose	Business					B			
	Study					B			
	Visiting friends					B			
	Shopping					B			
	Return home					B			

B = Boolean, C = Continuous, D = Discrete.

The comparison of the calibration results for estimating induced demand reveals some common variables used by the authors, which are mainly variables explaining the socio-economic characteristics of the transport users. In particular, the gender variable in Cascetta and Coppola [23] (see Eqs. 6 and 7) and in Ren et al. [37] is specified as a

Table 3. Classification of variables used to estimate distribution demand.

Class	Variable	[34]		[39]	
		B	NB	B	NB
Territorial economy	GDP	C			
	Business attactive	C			
	Non business attactive		C		
	Working population	C			
LoS	Time			C	C
	Tariff			C	C
	Frequency			C	C
Logsum	Mode-choice	C	C		

C = Continuous.

Boolean variable, which is equal to 1 if the user is a male, and 0 if the user is a female. The results of the calibration show that the value of the parameter is positive in the first case and negative in the second one. According to Ren et al. [37], the probability of increase the travel frequency in presence of HSR is higher among females in the Chinese market, while an opposite result has been obtained by Cascetta and Coppola [23] for the Italian market.

5 Conclusion

The study of the existing literature on the impacts that HSR generate on induced demand showed the presence of few works on this topic.

The induced demand generated by HSR in a territory is defined as the number of users who make new trips and increase the trip frequency on a given O-D relation. Considering the benefits related to accessibility, greenhouse gas reduction and economic development, the knowledge of the induced demand is crucial for the planning of the HSR network. The analysis presented in this paper described the current methodological advancement regarding HSR induced demand estimation. In particular, a summary of the results obtained in each paper was proposed. The comparison of the model results calibrated by a few authors revealed a discrepancy in the calibrated parameters. Among these, the "gender" parameter appears significant.

The conclusions derived from this literature review provide important insights for transport researchers, indicating the need for further research and analysis to deepen the understanding of the impact of HSR services on transport demand, especially considering the limited analysis of the induced demand component. More generally, the basic constraints consist in the difficulty to develop specific survey and subsequent analysis and modelling regarding the induced demand.

Future research will concern the construction of aggregate models for estimating the demand induced by the opening of HSR services in underdeveloped areas, with an

application to the Rome-Reggio Calabria relationship (Italy), with the aim of analysing the effects of High-Speed Railway systems on the variation of travel frequency.

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