

Research Article

Passenger Mobility in a Discontinuous Space: Modelling Access/Egress to Maritime Barrier in a Case Study

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The present study analyses a transport system in a discontinuous space. Classical specifications of transport models cannot be applied directly when evaluating the influence of territorial discontinuity and related barriers on user behaviour. Adjustments are required for this specific case because studies relative to discontinuous spaces are limited. The influence concerns the different travel components (access, barrier, on board, and egress) and could impact travel choices (departure time, destination, mode, and path). In this paper, the models refer to access and egress components with a focus on the mode of travel choice level. The paper focusses on the influence of discontinuity, introducing some adjustments to the classical demand models used to simulate discontinuity crossing. The main variables influencing the user's choice, and their relative weight in discontinuous space, are investigated. These elements are fundamental for any planning and design procedures to improve the quality of mobility. In the paper, the case study of the Strait of Messina in southern Italy is analysed. In this case, the barrier is constituted by the sea that physically separates the two shores. In this work, only strait crossings via hydrofoil, from Reggio Calabria to Messina, are considered in random sample interviews.

1. Introduction

In this paper, problems related to temporal and spatial discontinuities in a transport system are studied. The issue is common to many European spatial planning and transport policies that aim to remove bottlenecks and barriers limiting the mobility of people and goods. For instance, the Trans-European Networks for Transport (TEN-T) [1] help “close gaps, remove bottlenecks, and eliminate technical barriers that exist between the transport networks of EU Member States” [2]. Moreover, planned TEN-T interventions pursue the objectives of removing bottlenecks and filling missing links. However, many academic research have not traditionally focussed on transport bottlenecks [3]. Considering the existing financial and environmental constraints, construction of new infrastructures is not the only solution. As an example, the importance of, and the problems related to, bottlenecks in public transport operations is highlighted by van Oort et al. [4]. As a consequence, a new approach to study and solve bottlenecks and barrier problems is needed.

In this context, it is crucial to develop travel demand models for transportation planning, as they can be used to estimate present and future demand [5–8], also considering recent research developments in the type of choice models [9].

In transport systems, behavioural demand models are typically studied (specified, calibrated, and validated) in continuous territories when simulating travellers' choices. In a territory with a discontinuity, two continuous areas are divided by a physical element (e.g., sea, lake, or river) and cannot be travelled using a single mode in a continuous time (i.e., pedestrian, bicycle, or private car on road). Users who travel only within the continuous area have many transport alternatives at their disposal (individual, collective, semicollective, and multimodal). However, for trips between two continuous areas, they are forced to use only multimode collective or semicollective alternatives with discontinuous services (i.e., pedestrian, bicycle, or private car on discontinuity ship service). The discontinuity may impact one or more travel choice levels (departure time, destination, mode, and

path). There is a great deal of literature on behaviour demand models for simulations of travel users' choices in a continuous space [10, 11]. However, similar studies considering the presence of a discontinuity in the spaces are limited.

This research is in the field of demand models related to a discontinuous space. There are three main components in the travel choice for a discontinuous space: *access* (i.e., reaching the terminal from the point of origin), *barrier* (i.e., waiting at the terminal for the service), *on board* crossing the discontinuity (i.e., moving from the terminal located in the area of origin to the terminal located in the destination area), and *egress* (i.e., reaching the final destination from the terminal). In this context, adjustments to the classical specification of the models for the simulation of user choices are required for each travel component (i.e., users could have different choice set alternatives in the same trip in the three components).

This paper considers models with reference to the mode adopted for the access and egress component. The main goals of the paper are to consider the influence of discontinuity on the travel choice; to introduce adjustments to the classical demand model to take account of the mode choice for access and egress given a service crossing the discontinuity; and to apply the model (specification, calibration, and validation) in a case study based on a survey. This paper is innovative in that it proposes models representing passenger mobility in the presence of a space discontinuity.

The problem is (a) relevant and (b) general. (a) It is relevant because many urbanised areas in the real world are separated by a discontinuity, and traditional and consolidated models cannot be directly applied to design and planning. The innovation also relates to the specification, calibration, and validation of a specific model for the discontinuity. It cannot be simulated by a traditional approach adopted for a waiting trip component in transit system [12]. Instead, it has to be considered as a model evaluated in the context of an entire trip. (b) It is general because it considers the problem of access and egress models with experimentation in a real case where a territory serves as a natural laboratory. The case study examined is the Strait of Messina Area (Italy), including the metropolitan cities of Messina (Sicily) and Reggio Calabria (Calabria). This area represents a whole because of its unique geographic characteristics (minimum strait width of just 3.2 km) and consequently the close relationships between the two shores of the Strait. The presence of activities in both cities generates significant flows of people, despite poor transportation system integration and the considerable amount of time spent in this short-medium distance mobility. The Strait Area also involves long distance trips to and from Sicily. Both freight and passenger flows in the area are significant. This work focusses on the second.

In the study, one segment of strait-crossing passenger mobility is focussed. The goal of the present work is to model the mode choice only for users having previously decided to cross the Strait of Messina by hydrofoil on the Reggio Calabria–Messina route. For achieving this goal, a survey was conducted, and the obtained data are used to calibrate and validate a behavioural model.

The paper has the following structure. Section 2 presents a brief literature review. Section 3 presents the proposed method and illustrates the problem of mobility with barrier (Section 3.1). The method to analyse the problem is proposed for the current (Section 3.2.1) and scenario configurations (Section 3.2.2) in order to support decision makers and planners (Section 3.3). In Section 4, the proposed method is applied to the case study to analyse passenger mobility with a barrier constituted by the Strait of Messina, located in southern Italy (Sections 4.1 and 4.2). The applications concern current (Section 4.2.1) and scenario configurations (Section 4.2.2), producing results useful for decision makers and planners (Section 4.3). At last, Section 5 offers conclusions with the main results and considerations.

2. Literature Review

A transport system includes a supply component, including infrastructures and services offered in continuous or discontinuous spaces, and a demand component, referring to user travel needs. These two components interact, generating flows in continuous or discontinuous transport networks.

Referring to the continuous space context, and adopting a network approach, some elements of the supply component (e.g., car, pedestrian, etc.) are generally represented as continuous systems [10]. Other elements (e.g., transit systems) have to be represented as discontinuous systems [13]. In this context, discontinuity in infrastructures and services becomes a constraint [14, 15].

Referring to the discontinuous space context, some authors have considered territorial discontinuity as physical constraints that act as an absolute or relative barrier to movements and exchanges [16–18]. These barriers are related to the presence of physical, and/or topographical features (e.g., a sea, lake, or river, etc.) [19]. The impacts of a discontinuous space in a transport system are significant for island accessibility. In fact, on islands, discontinuity of space results in poor accessibility, since they can only be accessed by sea or air transport services [20, 21].

This condition implies the presence of specific infrastructures (e.g., a port) and services (e.g., maritime services) that allow users to overcome the barriers. Rodrigue et al. [22] distinguish between absolute barriers, where modal change is constrained, and relative barriers, where path choice is constrained. Both cases imply a friction on movement.

Barriers influence accessibility and mobility in relation to the interaction between territorial and transport systems [23]. A specific issue is related to island accessibility, where the discontinuity of space makes private transport an unavailable alternative with respect to continental areas [24]. In these specific cases, access and egress distances influence modal choice [25]. Regarding these problems, two interesting works concern the Bosphorus Strait crossing in Istanbul. The first describes the effects of the introduction of the BRT system that crosses the Bosphorus Strait in Istanbul, including the consequent modal shift for trips between the European and Asian shores of the strait [26]. The second provides an overview of economic, social, and environmental impacts of Europe-Asia crossing transportation policies on Istanbul over

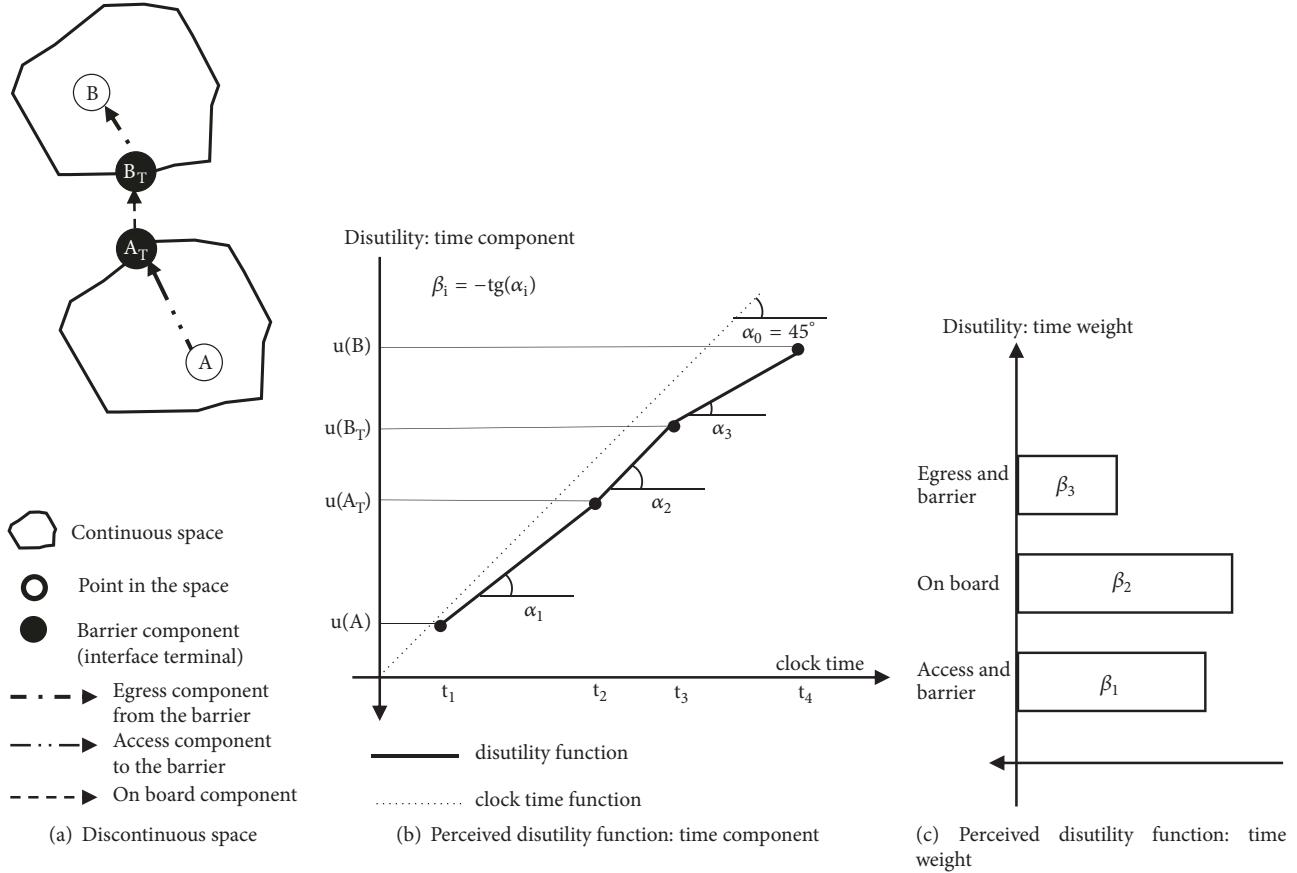


FIGURE 1: Travel in discontinuous space: Disutility function.

time [27]. Thus, there appears to be a lack of travel demand modelling for discontinuous territories. The schematisation of a discontinuous transportation network generally includes terminal nodes that are connected to their respective network and allow intermodal transport in order to overcome physical discontinuity.

The problem of discontinuity and barriers and their implications on user behaviours on travel choices are not extensively explored in the literature. In applications, simulation modelling of the discontinuity of space is generally represented as discontinuous transport systems in a continuous space. Consolidated approaches propose models to represent discontinuous transport services (e.g. transit services) adopting frequency-based [28] or schedule-based approaches [29, 30]. However, in most cases, the principal hypothesis is that discontinuous transport services are offered in a continuous space. The presence of discontinuity in the space limits available travel alternatives, forcing users to use at least two transport modes. Few studies explicitly consider the effects on user behaviour and travel choices in the presence of a discontinuity in the spaces.

For these reasons, models estimating current and future transport demand in a discontinuous space have to be constructed (specified, calibrated, and validated) [10]. The modelling approach adopted in this paper is derived from a classical random utility theory. The objective here is to clarify the implications of space discontinuity in transport

modelling. For this reason, classical tools like Revealed Preferences (RP) and Stated Preferences (SP) surveys on a sample of users are adopted to support construction of the simulation model [31].

3. Modelling Discontinuity

3.1. Mobility with Barrier. The problem is how to represent a transportation system (supply, demand, and interactions) in a discontinuous space. The main difference with respect to a trip in a continuous space is the lack of alternatives to complete the trip using a single mode of transport between two points in the discontinuous space. Also, in a continuous space, there are transport supply alternatives with discontinuity (e.g., transit services). In any case, there is always at least one alternative without interruptions in a continuous space.

The diagram in Figure 1 shows an example of discontinuity effects in a transport system. In the example, the trips between A and A_T and between B_T and B can be completed in the continuous space. In these types of trips, there are no interruptions (or barriers) and there is at least one mode of transport (for instance, pedestrian mode) to complete them. In the same diagram, the trip between A and B presents a discontinuity component. To complete this trip, users are forced to change the transport mode and are constrained by the service schedule. They must use discontinuous services linking interface terminals between continuous and

discontinuous spaces (such as two ports). More precisely, to travel between two continuous spaces, users are constrained by schedules and travel times of transport services connecting A_T and B_T . The individual transport modes for traveling in a continuous space (i.e., pedestrian, bicycle, or private car on road) are not available to overcome the discontinuity in the space (between A_T and B_T).

In this case, the trip has the following components:

- (i) an *access component* representing the part of the trip from the point of origin (A in Figure 1(a)) to the departure terminal in the same space (A_T in Figure 1(a)). Available transport modes and services for this trip can be continuous or discontinuous, characterising a user disutility specification (e.g., in Figure 1(b), disutility is relative to the time variable only);
- (ii) a *barrier component* representing the part of the trip within the barrier (A_T in Figure 1(a)) where some operations must be performed in the departure phase in order to use the transit services covering the discontinuity (e.g., check-in, waiting, ticket acquisition, etc.) and in the arrival phase (e.g., discharge, etc.). These terminals are constrained points in the continuous space belonging to the origin (A in Figure 1(a)) and the continuous space belonging to the destination (B in Figure 1(a));
- (iii) an *on-board component* representing the part of the trip between the departure and arrival terminals (A_T and B_T in Figure 1(a)). The two terminals are linked by transport services that are discontinuous in time, characterised by a speed and a capacity (Figure 1(a));
- (iv) an *egress component* representing the part of the trip from the arrival terminal point (B_T in Figure 1(a)) to the destination point (B in Figure 1(a)) in the same continuous space. Available transport modes and services for this trip can be continuous or discontinuous as in the access component (Figure 1(a)).

The barrier is a bottleneck in the transport system. Adopting a behavioural approach, a generic user perceives each trip component in a different way. It is possible to estimate the disutilities for each trip component. For instance, Figure 1(b) shows the disutility function: the time component for a user moving from A to B is represented as an example. The function varies with time. The user perceives each time component with a different weight (β_i), that is, the slope of the correspondent part of the disutility function. To obtain the β_i values, a survey is needed to specify and calibrate a behavioural model simulating travel choices in a discontinuous space. In the example, the *on-board*, *egress* and *barrier* components have the maximum and the minimum weight values, respectively (Figure 1(c)).

3.2. Proposed Modelling Approach. The proposed method aims to analyse users' perceptions of the discontinuity in terms of quantitative variables describing travel disutility. The characteristics of the current configuration of transport systems (in continuous and discontinuous spaces) are inputs

of the method. These are composed of infrastructures (linear and punctual), services (timetables, running times, fares, etc.), and territory activities (residential, production, commercial, etc.). The problem can be studied in two different approaches.

- (i) The first (*big data analytics*) consists in collecting data on the RP of users from different sources in real time or in off-time. The collected data allow planners to elaborate statistical indicators for the current discontinuity configuration. From the collected data, some statistical results, relative to historical configuration, can be obtained for each temporal period, users category, and travel choice level (i.e., O/D matrices, trajectories, and level of service attributes). From this historical data traditional travel demand statistical models could be constructed. The forecasted effects related to interventions (or scenario configurations) to solve the discontinuity problems refer only to historical and current configuration. For instance, effects of introduction of a new travel alternative, not present in the current situation, are estimated with a statistical significance referred to the current configuration.
- (ii) The second (*transport models*) is an evolution of the first. The data and statistics obtained in the first way are inputs to model the current and scenario configurations. Indicators to evaluate users' RP behaviour on discontinuity can also be obtained for scenarios completely different from the present configuration. Moreover, data and their processing allow planners to design scenario configurations, to obtain feedback from users through SP survey data, and to simulate potential effects produced by interventions to solve discontinuity. With respect to the first approach, the statistical significance increases.

Indicators of user perceptions of the discontinuity in scenario configurations can be simulated by following the second way (this is not possible with the first). The proposed method supports transport planning in the selection of transport control variables (travel times, fares, costs, etc.) that influence travel choices in the presence of a discontinuity in a transport system. Figure 2 summarises the contents of the two ways. The structure of Sections 3 and 4 is also shown in relation to the entire proposed and applied method.

3.2.1. Current Configuration Modelling. The first phase aims to simulate current users' perceptions of a discontinuity by identifying quantitative variables that influence travel choices and related disutilities. To construct a simulation model (specification, calibration, and validation) an RP survey must be conducted. Descriptive and inferential statistical analysis is performed to estimate travel choice probabilities in relation to the variables and parameters representing travel disutility (e.g., times and costs). This allows analysts to identify variables representing users' perceptions in the current scenario.

Behavioural models are based on random utility theory and attempts to reproduce users' choice behaviour [32]. A

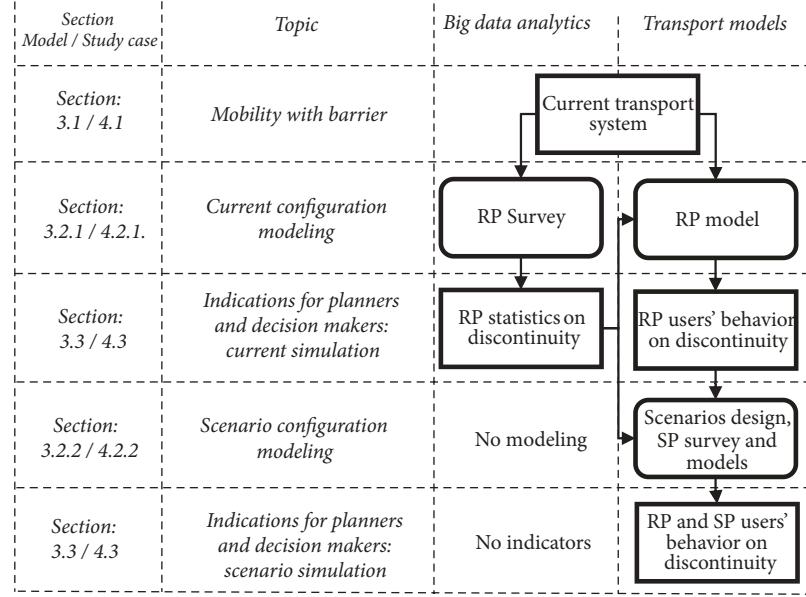


FIGURE 2: The proposed approach.

proper understanding of users' travel choices is essential in order to evaluate the ex ante effectiveness of possible transportation policies or services. The main assumption is that every individual is a rational decision-maker who maximises utility or minimises disutility. The user chooses an alternative from a finite choice set of mutually exclusive available alternatives. Each user assigns a perceived utility u^{RP} to each alternative m and selects the one that maximises utility.

For users, the perceived utility u is assumed to be a random variable with a known probability function. Its expected value is known as systematic utility v , which is generally assumed to be a linear combination of attributes, weighted by parameters (or coefficients) β . Different random utility model forms can be derived by assuming different joint probability distribution functions for the perceived utility U .

Note that an estimation of the parameters β could be obtained adopting big data analytics and traditional travel demand statistical models. However, parameters have a statistical significance referred only to current situation.

It is assumed that the travel disutility of the trip with mode m from a generic point A to a generic point B (u^{RP}_m) has the following functional dependency:

$$u^{RP}_m = \varphi(v^{RPc}_m, v^{RPd}_m, \beta^{RPc}_m, \beta^{RPd}_m) \quad (1)$$

where

v^{RPc}_m , is the vector of variables representing users' perceptions in the continuous space;

β^{RPc}_m , is the vector of parameters weighting variables in the continuous space;

v^{RPd}_m , is the vector of variables representing users' perceptions in the discontinuous space;

β^{RPd}_m , is the vector of parameters weighting variables in the discontinuous space.

The utility is not known with certainty by the analyst; thus u^{RP} might be represented in general by a vector of a random variable containing the utility relative to all modes. The expected value of this random variable (known as systematic utility) is assumed to be equal to v^{RP}_m :

$$v^{RP}_m = E(u^{RP}_m) \quad (2)$$

It can be assumed that it is the sum of the expected utility of variables representing users' perceptions in the continuous space ($\beta^{RPc}_m (T) v^{RPc}_m$) and discontinuous space ($\beta^{RPd}_m (T) v^{RPd}_m$):

$$v^{RPd}_m = \beta^{RPc}_m (T) v^{RPc}_m + \beta^{RPd}_m (T) v^{RPd}_m \quad (3)$$

where (T) stands for the transposed vector. Note that the systematic utility of the alternative is assumed to be the sum of two linear combinations of attributes weighted by parameters (or coefficients) β . The parameters are distinct for continuous and discontinuous spaces.

Starting from these disutilities it is possible to estimate travel choice probabilities for the current scenario. Under this hypothesis, although the selected alternative cannot be predicted, the probability that the decision-maker will select the alternative from his choice set can be expressed. The Multinomial Logit Model (MNL) is the simplest random utility model. Its specific assumptions are as follows: the perceived utilities are distributed as random Gumbel variables with scale parameter θ ; they are identically and independently distributed across alternatives (covariance of random residuals of any two alternatives is null); and they are identically and independently distributed across observations/individuals [33]. Referring to the same trip (A to B) and

to the current configuration, the MNL probability relative to the modal alternative m is [32]

$$p_{m}^{RP} = \psi(u_m^{RP}, \theta) = \frac{\exp(v_m^{RP}/\theta)}{\sum_m \exp(v_m^{RP}/\theta)} \quad (4)$$

where

ψ is the function that evaluates the probability for each alternative m for a given probability density function;

θ is the parameter of the probability density function.

Note that, considering a Gumbel probability density function,

- (i) the function ψ can be specified in a closed form;
- (ii) adding a linear specification of the expected value of u^{RP} , the parameter θ can be included in the β ; parameters β , including the parameter θ , can be calibrated using the RP survey with the maximum likelihood method.

In the case studied in this paper, the focus is on two aspects relating to the mode choice for access and egress. The first concerns the construction of the choice set that could be different for access and egress in the same trip. The second concerns the specification of the models that could be different in relation to the travel components. These adjustments are necessary to consider the discontinuity effects.

3.2.2. Scenario Configuration Modelling. By considering the current transport scenario and users' perception of the variables, the second phase aims to simulate users' perception of a discontinuity in relation to a set of planned transport scenarios. They are represented by infrastructure and service characteristics in order to reduce user disutilities related to discontinuity. Then an SP survey and a simulation model have to be performed. Each scenario is represented by a set of variations of the variables identified in the first phase. Planned scenarios are presented to a sample of travel users as potential future transport alternatives. The SP survey and model allow analysts to quantify the users' perception of the planned scenarios proposed to overcome discontinuity. For this reason, descriptive and inferential statistics are recalculated in order to estimate travel choice probabilities for each scenario when varying quantitative variables representing planned scenarios.

Considering a similar specification adopted in Section 3.2.1 (in all the notations of the variables, SP is adopted instead of RP), referring to the same trip (A to B) and to scenario configuration, the probability for the modal alternative m is

$$p_m^{SP} = \psi(u_m^{SP}, \theta) \quad (5)$$

Parameters β , including parameter θ , can be calibrated using an SP survey with the maximum likelihood method.

3.3. Indications for Planners and Decision Makers. The two described approaches (big data analytics and transport model) can support planners and decision makers in solving

problems related to the presence of a transport system in a discontinuous space. However, as already pointed out in Section 3.2, the possible indications that can be obtained using the two ways are very different.

Using *big data analytics*, planners and decision makers have to limit statistics on the current configuration to RP. Estimations of quantitative effects deriving from interventions on infrastructures and transport services to solve discontinuity with scenarios different from the current configuration are not available.

The *transport model* supports the transportation planning process in order to identify and quantify to what extent factors influence travel choices in continuous and discontinuous spaces. Factor quantification is essential to define and obtain an ex ante evaluation of effects produced by planned scenarios.

Modelling of discontinuity effects in the current and planned configurations allows planners to consider user needs and then to increase the sustainability of the proposed transport infrastructures and services. Quantitative effects estimated by planners support decision makers in planning, programming, and realising the proposed solutions. In particular, modelling and quantification of discontinuity effects support decision making process for the definition of the priority solutions order.

4. The Case Study

The aim of the present study is to develop an access/egress model for the Strait of Messina crossing for users who traversed the Strait by hydrofoil on the Reggio Calabria–Messina route. The structure of Section 4 is the same as Section 3. The Strait is a territorial discontinuity in the TEN-T Scandinavian Mediterranean Corridor.

4.1. Mobility with Barrier. The case study area is the Strait of Messina Area that includes the metropolitan cities of Messina (Sicily) and Reggio Calabria (Calabria). From a mobility point of view, the cities have strong relationships with each other and with their suburbs (short-medium distance mobility). The Strait Area also involves long distance trips to and from Sicily.

According to a recent estimate, total mobility in the Strait Area involves a flow of about 216,000 users/day on an average work day, most of whom (62%) travel by private car, and 38% by transit, including transport services in the Strait; work and school/university travel predominates (90%). Private automobile is the favourite transport mode (86%) for work-related commutes, while transit is preferred (74%) for study travel [34].

The mutual attraction between the urban areas of Messina and Reggio Calabria is expressed by the estimated number of strait crossings of about 21,000 users/day in both directions. Of these, about 61% are within the Strait Area, 18% originate or end inside the Strait Area, and 21% both originate and end outside the Strait Area [34]. In the port areas of Messina and Reggio Calabria, loaded and unloaded freight total 6.6 tons/year and 4.7 tons/year, respectively [35]. Approximately 3,000 passengers/day have been counted on an average

working day in the Reggio Calabria harbour node, for the Messina–Reggio Calabria and vice versa for the hydrofoil service alone. This relationship is slightly imbalanced towards the Sicilian side, which is more attractive than Calabria: 59% of trips are from Calabria to Sicily, while 41% are in the opposite direction [34]. Furthermore, 37.3% of trips are for work purposes and 26.1% for school or university purposes. Private motor transport is the favourite mode (56%) to access the harbour [34]. Poor integration in the transportation supply system and the physical discontinuity represented by the sea result in long travel times, with 82% of strait crossings by hydrofoil on the Messina–Reggio Calabria route taking between one and three hours [36].

Ferries are one of the available strait crossing modes for trains, motorised vehicles, and passengers, covering the Messina–Villa San Giovanni (RC) route. The other available strait-crossing mode is the hydrofoil service, a high-speed boat for passengers only. It covers the Messina–Reggio Calabria and Messina–Villa San Giovanni (RC) routes in both directions.

Of the set of available alternatives (ferries and hydrofoils) for crossing the discontinuity, the hydrofoil alternative connecting Messina (belonging to Sicilia region) and Reggio Calabria (belonging to Calabria region) is selected. This selection derives from the following considerations: Messina and Reggio Calabria are the main cities in the area, the majority of the population lives in these two centres, the alternative is specialised for passenger service, and the service is not available at night.

Due to the physical discontinuity causing different transportation conditions on the two shores, mode choice is analysed separately for the two parts of each trip, before and after the crossing: the first part (*access*), from the origin of the trip to Reggio Calabria harbour, and the second part (*egress*), from Messina harbour to the destination. Trips in access and egress have different characteristics and choice sets. So, two kinds of mode choice models have been developed for access and for egress, using the theory and models for travel demand presented in Section 3.2.

Three planned scenarios are considered: Scenario 1: integrated ticketing, time coordination and integrated ticketing for intermodal transit in the Strait Area involving urban public transport in Messina and Reggio Calabria cities and hydrofoil service; Scenario 2: direct bus, a bus service directly connecting Reggio Calabria to Messina, without transfers, including strait crossing by ferry via Villa San Giovanni; Scenario 3: confirmed, to confirm the chosen travel alternative in access and egress.

4.2. Proposed Modelling Approach. The current configuration is studied starting from an RP survey, while the scenario configurations are studied starting from an SP survey. Starting from the survey, RP and SP models are specified, calibrated, and validated.

It should be highlighted that the survey aims to represent only one segment of strait-crossing mobility. In addition, it should be underlined that, because of the period during which the survey was conducted (June 2017) and because of the cyclical variations of travel demand, high-school student

trips are not considered, although their share in the total number of this kind of trip is significant during the school year. Almost all users (90.6%) are commuters (workers and university students).

Strata were identified with each scheduled hydrofoil trip in a day and the number of interviews conducted for each *stratum* is proportional to its size. The number of definitively validated interviews is 245, while an average flow of 1,236 passengers/day was counted during the same period. Thus, an actual sampling rate of 19.8% was estimated. The main information asked of interviewees was as follows: origin and destination of the trip, trip purpose, hydrofoil departure time, departure time from place of origin and estimated arrival time at destination, transportation modes used in the travel chain to reach Reggio Calabria harbour (*access*) and to reach the destination from Messina harbour (*egress*), sex, age, employment, home-based trip, and frequency of the same trip. Lastly, an SP question was asked.

4.2.1. Current Configuration Modelling. An RP survey was conducted over three days in June 2017 at the hydrofoil service terminal in Reggio Calabria harbour, meaning that only users of this service travelling from Reggio Calabria to Messina were interviewed. The survey received the support of ATAM, the public transport company in Reggio Calabria. Once created, the database [37] was used as input in the model development process.

The method used is Simple Stratified Random Sampling, in which the population is divided into mutually exclusive groups of users (*strata*), whose number is known, and from which simple random samples of elements are drawn [10].

From the RP survey statistical data analysis, almost all of the investigated trips originated in the city of Reggio Calabria (86.1%). Similarly, most of the trips had Messina as their destination (80.4%). For simplification purposes, the chosen transportation modes were grouped in three main categories (walk, motorised, and transit), based on their characteristics. Reggio Calabria harbour is reached primarily via private vehicle, while egress in Messina harbour is distributed almost equally among modes.

The mode choice models developed in the present work are the behavioural model (Random Utility Models), and MNL, with different specifications for access and egress. The mode choice alternatives considered in the choice set are walking, motorised, and transit, with the same meaning as expressed above. Systematic utility functions of the three alternatives are a linear combination of the level of service attributes (travel times, monetary costs) and alternative specific individual attributes (home-based trips, walking distance, and trip purpose). Table 1 shows the model specification and all estimated parameters for the developed models and their statistical tests [36].

First, informal tests were conducted. All estimated parameters fulfilled sign conditions and presented expected values. The parameter for passengers whose home was the point of origin of the trip ($\beta_{o,home}$), referring only to the motorised mode, presented a positive value for the access model and a negative value for the egress model, reflecting mostly the availability of the motorised mode in access and

TABLE 1: Calibrated RP models.

	Name	U.o.m. attribute	Access model			Estimated* Value (t-Student)	Egress model			Estimated* Value (t-Student)
			Walk	Motorized	Transit		Walk	Motorized	Transit	
β_{time}	Travel time	Minutes	X	X	X	-0.0629 (-5.50)	X	X	X	-0.0422 (-4.02)
β_{cost}	Monetary cost	Euro		X	X	-0.3303 (-5.62)		X	X	-0.2728 (-5.36)
β_{o_home}	1 if home as origin	Dummy			X	1.338 (4.63)		X		-1.814 (-5.11)
$\beta_{dist2km}$	1 if walking distance ≤ 2 km	Dummy	X			1.139 (5.27)		X		1.454 (3.45)
β_{uni}	1 if home-university purpose	Dummy							X	1.021 (3.45)
β_{work}	1 if home-work purpose	Dummy							X	1.767 (6.13)
Log-likelihood						-149.64				-169.52
ρ^2						0.437				0.365
McFadden ρ^2						0.316				0.365
χ^2						138.41				194.86
p.value						2.22E-16				2.22E-16
VOT						11.4 €/h				9.3 €/h

its unavailability in egress, on the other side of the Strait. All obtained VOTs (Value of Times, see, e.g., [38]) were in line with scientific literature.

Later, formal statistical tests were performed to verify certain hypotheses on parameter estimation. In the developed models, Student t-values were significant for a confidence level of 0.95. Likelihood Ratio values for estimated parameters exceeded the 95th percentile of the corresponding χ^2 variable. Therefore, the null hypothesis that the true model has * parameters (null or ASA) can be rejected with a very low probability of error. For the access model, ρ^2 and McFadden pseudo ρ^2 presented the values of 0.437 and 0.316, respectively, while both their values were 0.365 for the egress model.

Therefore, it can be stated that the presented models have a good fit and a fair ability to reproduce the mode choices in access and egress made by a sample of users crossing the Strait of Messina from Reggio Calabria to Messina by hydrofoil.

4.2.2. Scenario Configuration Modelling. SP surveys investigate individuals' preferences for services or policies that do not currently exist [31]. The choice contexts proposed to users refer to hypothetical design scenarios. By conducting SP surveys, new and currently unavailable choice alternatives and new model attributes can be introduced, relevant attribute variability can be checked, and generally more information can be obtained. However, with SP surveys, some deviations in data analysis and in calibrated models are introduced, derived from the user's possible different behaviour between the stated and the actual choice in the new scenario when realised, because of a lack of relevant attributes, justification

bias, and so on [10]. Among the questions, users were asked to indicate which option they would choose for the same trip in the scenario configurations.

From the SP survey statistical data analysis, the integrated ticketing alternative with time coordination is the preferred one (60.8%). Indeed, about 60% of interviewees stated they would be willing to switch to public transit if time coordination and integrated ticketing policies were implemented. About 25% would continue to use their motorised vehicles, while 12.8% of motorised users in access and 18.3% in egress would choose the direct bus service.

The present section models the possible modal shift in the hypothetical scenarios presented to the users in the SP question, for those choosing motorised mode in access in the current context (152 users, 62.8%). The mode choice model is MNL. The alternative scenarios considered in the choice set are as follows: 1 – integrated ticketing; 2 – direct bus RC – Villa S.G. – ME; 3 – confirmed. They refer to both the first portion of the trip (*access*) and the Strait crossing phase by hydrofoil in the first and third alternatives, and by ferry in the second one. The SP question relates to the three scenario travel alternatives (1, 2, and 3 in Table 2) represented in terms of time and cost. Among the alternatives, Alternative 3 confirms the current configuration, while the other two alternatives are easily identifiable by users because they introduce variations to the current configuration. In addition, most users cross the strait regularly and are familiar with the transport system in the area. These aspects should reduce the bias in the SP survey.

Table 2 shows the model specification and all estimated parameters for the developed model and their statistical tests. Two models are proposed: the difference between them

TABLE 2: Calibrated SP models.

	Name	U.o.m. attribute	(1) Integrated ticketing	(2) Direct bus (RC – Villa S.G. – ME)	(3) Confirmed	Estimated value (t-Student)
β_{time}	Travel time	Minutes	X	X	X	-0.0268 (-2.26)
β_{timeB}	Travel time for barrier	Minutes	X	X	X	-0.0091 (-0.37)
β_{timeA}	Travel time for access	Minutes	X	X	X	-0.0400 (-2.44)
β_{cost}	Monetary cost	Euro	X	X	X	-0.1229 (-0.87) -0.1288 (-0.91)
β_{o_home}	1 if home as origin	Dummy	X			0.6374 (2.21) 0.5591 (1.83)
β_{centre}	1 if origin in city centre	Dummy	X			0.5521 (1.91) 0.4122 (1.14)
β_{uni}	1 if home- university purpose	Dummy	X			0.900 (2.22) 0.9190 (2.26)
Log-likelihood						-130.71 -129.2
ρ^2						0.217 0.226
McFadden ρ^2						0.063 0.073
χ^2						17.43 20.45
p.value						5.8E-4 1.4E-4
VOT						13.1 €/h 4.26 €/h
						18.64 €/h

concerns the travel time that is considered aggregated or disaggregated for *access* and *barrier* trip components.

All estimated parameters fulfil sign conditions and present expected values. The weight of access and barrier time is significantly different. The other parameters refer to the integrated ticketing alternative and present positive values, expressing the positive relation between the users with the characteristics represented by the parameters and their availability to shift to public transport mode.

Student t-values for almost all the estimated parameters are significant for a confidence level of 0.95. Only the parameters related to monetary cost (β_{cost}) and travel time for the barrier (β_{timeB}) are not significant. Indeed, motorised users do not seem overly concerned by the monetary costs in this context, but care mostly about the time spent travelling. Furthermore, the time component to access the terminal is much more significant than the time spent overcoming the barrier. The Likelihood Ratio value for estimated parameters exceeds the 95th percentile of the corresponding χ^2 variable. Therefore, the null hypothesis that the true model has * parameters (null or ASA) can be rejected with a very low probability of error. Also, the VOTs agree with the scientific literature with significant different values for access and barrier. Goodness of fit index ρ^2 - is not very high (0.217 or 0.226), probably because the hypothetical scenarios, which include a new travel mode alternative and new policies for intermodal public transport, are not very clear to the interviewed users. Thus, the answers may be scattered and illogical. However, as highlighted above, these deviations are part and parcel of an SP survey.

4.3. Indications for Planners and Decision Makers. The results of the statistical analysis obtained following the *big data analytics* approach provide limited indications for planners and decision makers. Statistics on RP travel choices are available only for the current configuration. There are no provisional estimations for scenario configurations.

The results obtained following the *transport models* approach provide simulations of user behaviours in the current and scenario configurations (Sections 4.2.1 and 4.2.2). Several indications for planners and decision makers are reported below.

A first indication concerns users' perception of travel time with respect to the access and the barrier trip components. Access time is significant in terms of the Student t-value, while the barrier time is not significant. This confirms that users take access time into high consideration, due to service discontinuity and the absence of any other continuous alternative. Another indication concerns the monetary cost that is not significant in terms of Student t-value in both cases.

Figure 3 summarises the disutility of travel time for the access and barrier components. Note that the access time component has a weighting about four times greater than the barrier time component (Figure 3(c)).

These results can be used to define and evaluate alternative transport scenarios and specific interventions aimed to limit space discontinuity effects. In particular,

- (i) the relevant role of travel time, compared to other disutility variables, indicates that interventions to reduce it are needed;

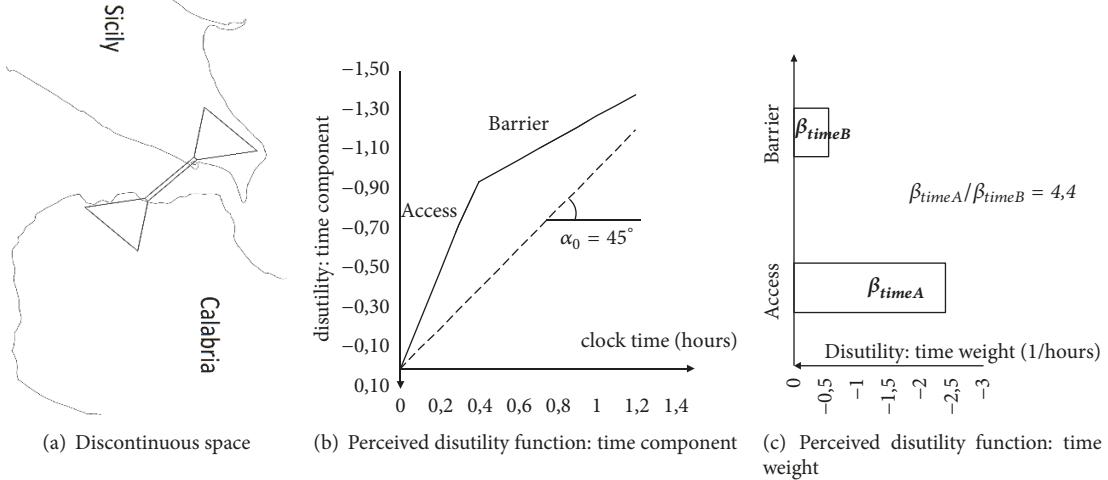


FIGURE 3: Travel in discontinuous space: The case study.

- (ii) the relevant role of access time, compared to barrier time, indicates the need of interventions to improve infrastructures and services connecting the terminal to its catchment area.

Figure 4 reports choice probability as a function of an attribute variation. The figure has three rows and two columns. Each row relates to a single possible scenario; the first column is for the travel time variation and the second column for the monetary cost variation only in the scenario reported in the row. For a fixed value of the attribute's percentage variation, the observed probability slope

- (i) (comparing columns) is more elastic comparing percentage variation in travel time with respect to monetary cost. This comparison provides information on the importance users assign to the time variation with respect to the cost variation.
- (ii) (comparing rows) assumes the maximum value in the integrated ticketing scenario and is similar to the direct bus scenario. This result provides information about the importance of realising interventions encouraging integrated ticketing to travel in the study area.
- (iii) (observing third row) is slightly elastic to time and cost in the current configuration (*confirmed*). This result indicates that users potentially prefer new scenarios with respect to the current configuration.

5. Concluding Remarks and Further Developments

This paper presents an analysis of transport systems in a discontinuous territory. A specific focus concerns users' perception of discontinuity in travel disutility. The proposed method studies the problem in two approaches:

- (i) The first is based on statistical analyses in the context of a *big data analytics* approach. The results and

information for planners and decision makers are limited to analysing the current configuration.

- (ii) The second is based on the *transport model* approach constructed using collected data obtained in the first way. The results and information for planners and decision makers are available for both the current and scenario configurations.

The proposed approach has been experimented to study mobility in a territory in southern Italy characterised by territorial discontinuity created by the Strait of Messina. For this study area, a survey was conducted, from which some statistical results have been obtained. These data support transport model specification and calibration. In particular, two mode choice models have been developed. The application focusses only on strait crossings by hydrofoil on the specific route from Reggio Calabria to Messina. The physical discontinuity generates different transportation conditions on either shore. For this reason, two different transport mode choice models are developed for the two parts of a generic trip between the two cities through the urban harbours. The first represents trips from the point of origin to Reggio Calabria harbour (*access*), and the second represents trips from Messina harbour to the destination (*egress*). The choice set includes walking, motorised, and transit modes.

The models proved fully satisfactory, since all parameters are significant and their validation tests provide good results. Moreover, VOT, ρ^2 , and McFadden's pseudo ρ^2 also presented values in line with the scientific literature. Conducting a second survey on the same population of users, with a different sample, and checking frequencies of choice could be a further step to verify the models' ability to reproduce user choices.

The results can be considered as the first step of the research. The results reported in the paper are derived from numerous tests in the specification-calibration-validation process. Many trial and error specifications were tested, also considering the same specification for the utility of the three travel components as a whole. These tests do not provide

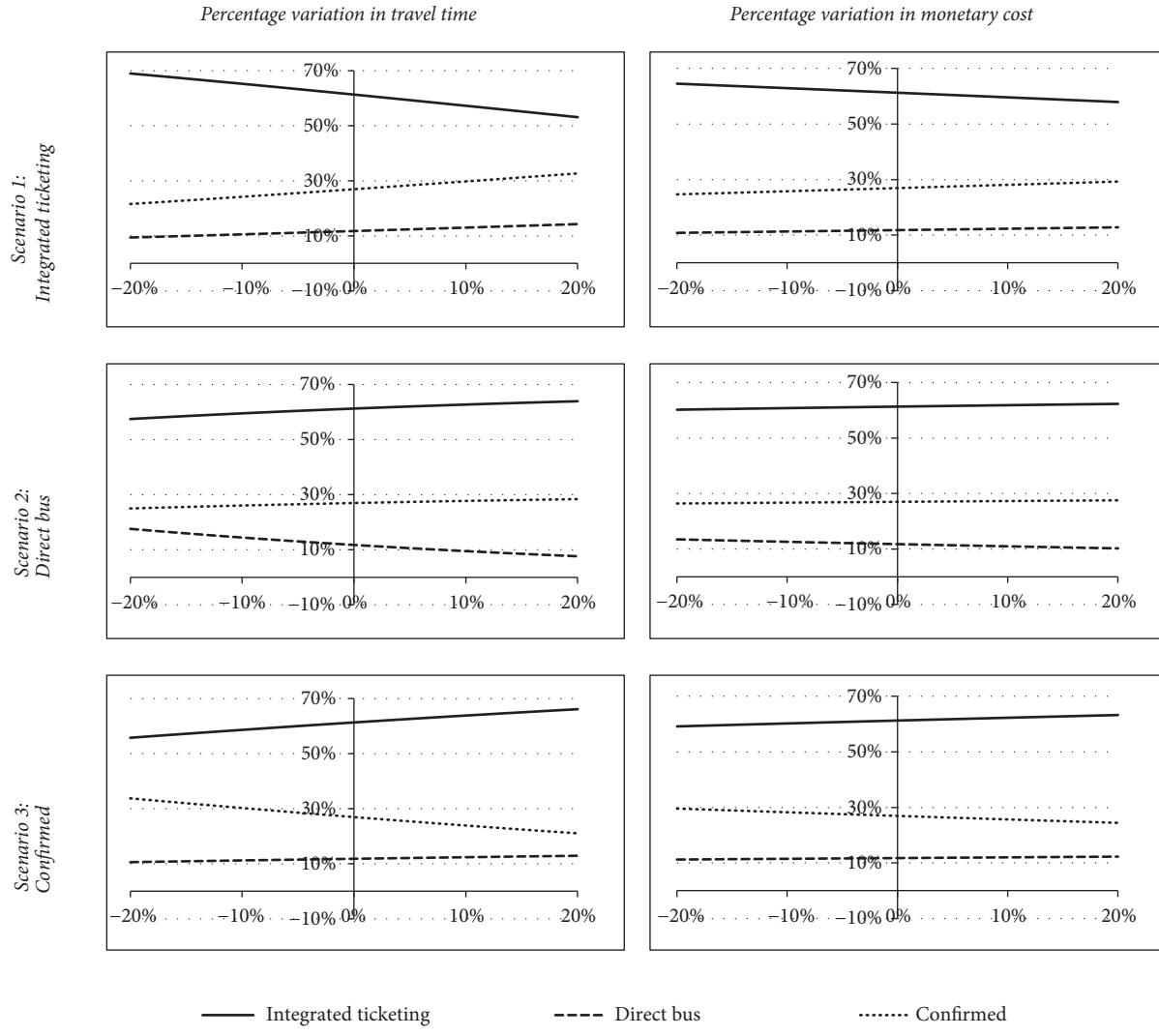


FIGURE 4: SP choice probability with respect to the variation of travel time or cost in one alternative.

significant statistical results, only when two different access and egress models are adopted do the statistical results give good results.

All of the results obtained confirm that user behaviour is different when traveling in a discontinuous space with respect to a trip in a continuous space. The differences have to be considered by planners and decision makers when defining interventions to limit discontinuity effects. The results obtained for the case study show the relative level of importance users assign to different trip components. These results indicate that it is essential to define interventions to improve intermodality and mobility integration for discontinuous territories. For instance, SP data analysis highlighted that hydrofoil users seem very interested in integrated ticketing and time coordination policies for public transport in the Strait Area. A mode choice model, including strait crossings by hydrofoil and by ferry in both directions, could support transport planning in the study area by estimating a modal shift for each alternative scenario.

Two main lessons were learned. (a) In a real context, discontinuity in space has impacts on connectivity; it

creates time (e.g., schedule, availability during the day) and space constraints (e.g., few terminals and unavailability of individual transport mode). (b) In the modelling context, adjustments simulating discontinuity effects are required in the classical demand model.

The results show some differences between user behaviour in the presence of a discontinuity in space. Referring to the specific case study, the role of travel time —and in particular access time, spent on reaching the terminal—emerges among disutility variables. This is one of the main peculiarities of the research topic.

Further developments regard extensions of the proposed method and relative applications. In relation to the model extension, a larger sample could be considered to simulate the entire trip chain and other demand components. Effects of discontinuity on others travel choice levels different from mode choice (departure time, destination, mode, and path) have to be studied. Additionally, the effects of attributes (i.e., costs, frequency) need to be investigated in order to estimate the measurement of discontinuity on travel behaviour.

These future research directions depend on the availability of other data that could be obtained by designing and implementing a mobility monitoring system for the study area. The monitoring centre could also be useful for operators and system managers to help them better design and plan the transport system. The problem can be studied in the context of emerging Mobility as a Service (MaaS).

The problem related to model transferability needs to be studied in detail, considering that each area with discontinuity has specific characteristics that are very often different from other areas. In relation to applications, an extension of the survey campaign to the entire area, involving short, medium, and long-distance trips, could be conducted in the study area in order to develop more comprehensive mode choice models. These can be very helpful in assessing possible future transportation policies, since they allow modal choice simulation in design scenarios developed on the basis of imposed goals and restrictions.

Data Availability

Data are obtained during the course of Master on Transport System Management and Logistics at the Mediterranea University of Reggio Calabria. Data are restricted for privacy and commercial confidentiality.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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