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Cost functions for rural and mixed footpaths

Domenico Gattuso[1], Gaetana Rubino[1*], Domenica Pellicanò[1]

[1]Mediterranea University, via R.Zehender, Reggio Calabria, 89124, Italy

[*]Corresponding author. E-mail address: gaetana.rubino@unirc.it

Abstract

In the context of transport studies, sustainable mobility is increasingly occupying an important space. Sustainability is not only a principle to be pursued by reducing the impacts of vehicle travel, but an important result to be achieved by promoting healthy lifestyles based on active mobility, i.e. walking and cycling. This applies both to "compulsory" mobility, i.e. for travel due to professional or study reasons, but also for leisure or tourist mobility. This paper focuses on active mobility for tourism and, in particular, on pedestrian itineraries in the extra-urban area. An innovative approach aimed at determining cost functions to qualify hiking-type routes is proposed. The outcome of the research allows to highlight the specific characteristics that lead to differentiating the cost functions in pedestrian mobility for tourism reasons from the traditional functions. Furthermore, a specific investigation methodology is introduced which should allow to arrive at the determination of mathematical models, calibrated on a statistical basis starting from the specified cost functions. This represents the fundamental basis in terms of mathematical modelling on which subsequent simulations can be based. Indeed, the introduction of any digital innovation or simulation model in the analysis of active mobility cannot be separated from an upstream analysis of the pedestrian mobility models as well as their calibration. Walking is the simplest human activity but no less important in terms of impact on the challenges of Agenda 2030 that the States are facing with great determination.

Keywords: walkability; cost function; active mobility; pedestrian mobility

1. Introduction

Sustainability is a key word in development policies and scientific research is naturally strongly oriented towards supporting actions aimed at increasing its scope. Even studies in the field of transport, in many cases, tend to follow an approach based on the three pillars of sustainability: economic, social and environmental. It is the area ofsustainable mobility which translates on the one hand into the reduction of the impacts of forms of vehicular mobility and, on the other, into the promotion of non-vehicular forms of mobility, i.e. the so-called "active mobility", based on energy kinetics produced by people moving on foot or by bicycle. For years research has been studying the relationship between the infrastructural characteristics of pedestrian paths and the propensity to favour walking. In urban contexts, in particular, thanks to the measurement of a series of indices and indicators, the walkability of some neighbourhoods, urban areas or, more extensively, of cities is evaluated (Cerema, 2021; Hutabarat Lo, 2009; Krambeck, 2006).

These studies also include innovative data collection methods (for example through satellite maps) and new tools for representing walkability based on new digital technologies and simulation (Yang et al., 2019; Cleland et al., 2021; Kasraian et al., 2021; Kim, 2022; Ng et al., 2023).

The study of models centred on pedestrian networks goes in the direction of the promotion of services and infrastructures intended to facilitate pedestrian mode. This has numerous implications: first of all for the purpose of encouraging sustainable mobility par excellence (with the benefits that this entails from an economic, social and environmental point of view); furthermore, the promotion of a new approach to urban planning, centred on the harmonious development of cities where the focus is on people and not on the vehicular infrastructure; and still the enhancement of the natural and landscape heritage, not only for purely aesthetic purposes, but by virtue of an urban regeneration purpose that reconsiders the most fragile and peripheral areas making them meeting areas and social inclusion; finally, the promotion of awareness on the part of citizens, economic operators and institutions regarding the heritage of their territory for tourism purposes.

The paper focuses attention on pedestrian mobility for tourist reasons with particular reference to extra-urban or mixed areas. An approach aimed at the determination and characterization of cost functions relating to excursion-type routes is proposed. Furthermore, a specific investigation methodology is introduced which should allow for the calibration of mathematical models, on a statistical basis, starting from the specified cost functions.

In section 2, the representation of the transport supply system through cost functions is illustrated, an approach aimed at identifying mathematical models for the study of mobility systems. Section 3 focuses on pedestrian mobility. First of all, in subsection 3.1, the state of the art of research on the topic is reviewed. Subsequently, in the following subsection (3.2), the pedestrian itineraries, with specific reference to the tourist and excursion ones, are described and explored. Finally, in the last subsection (3.3) the cost functions for pedestrians traveling on tourist itineraries are presented. Section 4 describes the fundamental passage between the specification of the cost functions and the presentation of the model which can also be used in simulation. The study results are described in the last section 5.

2. Mobility cost functions and models

The transport system is defined as a set of components and reciprocal relationships which carry out the production and consumption of the transport service in a given environment (Cascetta, 1990). The transport system can be divided into two subsystems. The mobility demand subsystem, including the users of the service, and the transport supply subsystem, which includes the components (both physical and organizational) involved in the production of the transport service. It is evident that, in reality, the transport system constantly interacts with the more general system of activities, including all the components that influence the transport system in a given historical moment and in a given place (e.g. current legislation, partner characteristics demographics, business structure, etc.).

For the purpose of analysing the transport system, mathematical models are widely used; by their nature, they represent simplifications of reality and are interesting tools for performance assessment of the system itself for descriptive or predictive purposes.

The transport supply system is modelled using network theory and represented by graphs. A graph *G* consists of a set of nodes *N* and a set of pairs of nodes belonging to *N*, called branches or links *L*; concisely we can write: *G= (N, L)*. The graph becomes a transport network when quantitative transport characteristics are associated; typically, the links and nodes of the graph are associated with impedances or "cost functions (*FC*)", for example a travel time or other charges borne by those who move on the network. A network can ultimately be assumed as *R = (N, L, FC)*.

The transport cost of a link is defined as a scalar quantity which summarizes the various cost items incurred by users as perceived and evaluated by them. Therefore, in the literature, travel cost measures users' aversion to traveling the link itself. Since the transport cost generally includes non-homogeneous quantities, it is practical to carry out a process of homogenization of the variables. To the more usual quantity used (time) it will be possible to add quantities of a different nature (cost, stress, etc.) after conversion into the same unit of measurement by means of mutual substitution coefficients. This leads to a "generalized cost" of transport, a cost perceived on average by users.

Generally, in vehicular mobility analyses, we refer to an average user, assuming a single cost function for all users on a link or in correspondence with a node.

At the transport network scale, a path cost vector can be defined, i.e. a vector $\boldsymbol{c}$ whose generic component c_{ij} is the cost of transport on the path (i,j). The cost can simply be the travel time or, as mentioned, a generalized cost.

Assuming stationary operation, the link flow is defined as the average number of users traveling the link. Therefore, one can define a link flow vector, i.e. a vector $\boldsymbol{f}$ whose generic component f_{ij} represents the link flow *(i,j)*.

Indicating the link with a scalar reference we will define c_i and f_i respectively the cost and the flow on the *i-th* link.

The quantities referred to the link can also refer to a path, i.e. a concatenated succession of links. The cost of the route C_k (1) will be defined as the cost perceived by the average user for traveling a path *K* and it will be calculated as the sum of the costs of the links that make up the route:

$$C_K = \sum_i a_{iK}\, c_i \qquad (1)$$

That is, in matrix form:

$$\mathbf{C} = \mathbf{A}^T \mathbf{c} \qquad (2)$$

where $\boldsymbol{C}$ is the path cost vector with components C_K, $\mathbf{A}^T$, is the transpose of the link-path incidence matrix and $\boldsymbol{c}$ is the link cost vector (2). The link-path incidence matrix **A** is a matrix in which each line represents a link of the graph and each column corresponds to an itinerary; the element of the matrix in position *ij* (a_{ij}) is equal to 1 if the link corresponding to the i-th line is part of the itinerary corresponding to the i-th column; otherwise it is zero.

In the same way, the path flow vector is defined as the vector ***F*** whose generic component F_K is made up of the number of users traveling the route *K* in the unit of time (3).

Finally, it is possible to determine the flow (4) that travels along a link *i* as the sum of the flows along this link:

$$f_i = \sum_K \quad k\ \boldsymbol{a}_{iK}\ \boldsymbol{F}_K \qquad (3)$$

That is, in matrix form:

$$\mathbf{f} = \mathbf{A}\ \mathbf{F} \qquad (4)$$

The transport cost perceived by a user is not always constant, but depends on several factors; for this reason, it is preferable to assume a cost function to be associated with a link of the network; this function is the tool by which it is possible to calculate an average transport cost for a generic user (vehicle) traveling a given link according to the flows of users (vehicles) traveling the link itself.

Each link of a network could be characterized by a specific cost function; however, this would make the analyst's work particularly onerous; it is generally preferred to assume cost functions representative of the type of infrastructure or network node. The cost function becomes a cost model after the calibration, i.e. with the determination of the scalar parameters associated with the single variables of the function.

It should be noted that the cost functions in transport system theory are different from the cost functions used in micro-economics. In fact, while in economics the cost function relates the production cost of a good or service to the quantity produced, in the case of transport the function links the cost incurred by the users of a transport system to the quantity of users themselves. In the first case it is therefore a production cost, while in the second case it is a use cost.

Over time, the relationship between some quantities that make up the transport cost of a link and the flow of users who use the infrastructure has been highlighted, due to mutual interference between the various users which causes congestion phenomena. There is a maximum limit of users on the infrastructure per unit of time (capacity) such that, as the flow approaches this maximum value, the travel time for users increases. The generalized transport cost consists of a fixed component and a variable component which depends, due to congestion, on the other flows present on the infrastructure or on the network node.

As mentioned, to standardize the cost components that affect the generalized cost, a homogenization procedure must be carried out. The concept of *Value of Time* (*VoT*) is often taken into consideration, translating the time components into a monetary value or vice versa.

There are numerous cost functions identified by transport engineering with reference to road transport, public transport and pedestrian transport. With reference to road transport, the cost functions are often expressed as a function of the degree of saturation, i.e. the relationship between the flow on the link and its capacity. In the case of pedestrian mobility, however, some assumptions could be modified, as will be seen later in the discussion.

3. Pedestrian Mobility

3.1.1. State of art and recent studies on pedestrian mobility

The study of pedestrian mobility according to an engineering approach was started by Fruin in 1971, relating the comfort of the pedestrian infrastructures with different types of pedestrians. This formed the basis for the Year 2000 version of the Transportation Research Board's (TRB) Road Capacity Manual (HCM) which focuses attention on pedestrian runoff, making it comfortable through increased available space and elimination of obstacles.

Levels of Service (*LoS*) were also introduced for pedestrians, linking them to metrics similar to those already used for vehicular mobility, i.e. space available to the pedestrian, capacity, speed; ratio of sidewalk size to capacity. The 2010 version of the HCM specifies that the main characteristic of pedestrian flows, speed, is influenced by individual characteristics (such as gender, presence of children, the elderly, PRM) or group characteristics (for example people who know each other and travel together, called "platoons").

The research carried out since the 1990s was oriented towards a multimodal approach, suitable for involving different indicators including: presence and continuity of sidewalks and pedestrian routes; accessibility of facilities to people with different abilities; directness of pedestrian paths and connectivity of the street network; connections to frequent transit services; ease and safety of crossings; visual interest; perceived or actual security (Ria Hutabarat Lo, 2009). Krambeck, in 2006, proposed the Global Walkability Index (GWI), formulated to compare different cities and made up of 14 variables, grouped into 3 categories of components.

The first approach, based on the flow capacity, differs from the second, multimodal, mainly for the planning scope and the measurement scale, one more detailed and focused on the transport planning and the other more macro-type and focused on the urban planning. An attempt to bridge the gap between the two methodological approaches has been made by F. Jaskiewicz in 2000. In the awareness that the concept of pedestrian service level (LoS) implies much more than volumes and capacities and assuming that pedestrian mobility is a valid transport alternative, he identified 9 criteria influencing LoS in order to classify the paths (Enclosure/Definition; Complexity of Path Network; Building Articulation; Complexity of Spaces; Overhangs/Awnings/Varied Roof Lines; Buffer; Shade Trees; Transparency; Physical Components).

Another line of study concerned the subjective perception of urban space by pedestrians. In this context we recall one of the pioneering works, proposed by Lynch K. (1984 which put the urban space in relation with the subjective satisfaction (and the consequent increase in active mobility) through the identification of five characteristic factors (Sense; Vitality; Fit; Access; Control) and of two transversal meta-criteria (Efficiency and Justice). Also Gehl in 1987 identified some elements (such as the slope, the pavement, the type of road) capable of enhance active mobility in public spaces.

Further contributions on the theme of urban factors capable of influencing active mobility come from the study of the correlation between socio-political factors and walkability carried out by E. Peñalosa (2000) and by Mason and Fredericksen (2006); as well as the correlation between neighbourhoods and active mobility, studied by Rosenblatt et al. (2005) and by Boer et al. (2007).

From 2005 onwards, the number of researches on walkability indicators increases significantly. They quote among others: Spoon (2005); Ewing et al. (2009); Maghelal et al. (2011).

Other types of research are more empirical and focus on the evaluation of a selection of indicators in urban contexts: Galanis and Eliou (2011), Cerin et al. (2011); Monteiro de Cambra (2012), while other studies have highlighted the important and close link between pedestrian infrastructure planning with the theme of sustainability: Moayedib et al., 2013; S. H. Rogers et al., 2013).

In 2015 methodological proposals have been elaborated, aimed at measuring walkability with specific software tools (Blečić et al., 2015; D'Alessandro D. et al., 2015).

In the last few years an important problem addressed was that relating to the detection and management of large amounts of data addressed in various works with the proposal of alternative solutions, such as the use of 2D and 3D GIS technologies (Yin L., 2017, Chiantera et al., 2018, Shatu et al., 2018) or other technological tools including open data, computer vision and machine learning.

Some research lines have been focused on the users point of view and on their socio-demographic characteristics (such as the elderly; children and adolescents; women, PMR) or on particular urban areas (such as university campuses, military areas), or on the consequences that Covid has had on pedestrian behaviour and walkability.

What emerges is that, especially at the outset, research has focused on pedestrian mobility with reference to emergency situations or escape by pedestrians.

In recent years some researchers have extended the field of investigation even to other aspects, introducing the theme of *walkability* as a key concept for combating, at a territorial level, phenomena such as sprawl and, broader level, pursuing sustainability and the objectives of the 2030 Agenda.

The benefits of an approach aimed at analysing and enhancing walkability are numerous (Cerema, 2021):

- health benefits: promoting walkability enhance an increase in active mobility, with consequent advantages in terms of physical well-being, the prevention and reduction of pathologies linked to sedentary life and, therefore, the promotion of outdoor activities; this translates into a decrease in the social cost of healthcare expenditure;
- economic benefits: the improvement of the urban environment and neighbourhoods to facilitate pedestrian mobility has a positive effect not only on the aesthetics and environmental liveability, but also on the value of economic activities and private properties (see Walk Score index);
- environmental benefits: pedestrian mobility is the only method of movement that does not have negative impacts on the environment, both directly and indirectly;
- benefits on intermodality: in cities whose mobility policies place the pedestrian at the centre, public transport is also seen at the service of "increased pedestrian traffic", i.e. as means aimed at increasing people's ability to move on foot;
- benefits in terms of accessibility: attention to the increase in walkability involves the implementation of accessibility-oriented strategies, with the creation of routes that are also accessible to people with reduced mobility (PRM); these paths not only favour the mobility of the weakest subjects, but facilitate the movements of all subjects;
- benefits in terms of uses: the natural (trees) or artificial (benches, fountains, toilets, etc.) elements present along a route can positively influence its attractiveness or, on the contrary, hinder its use (such as presence of obstructions or confusing signs); moreover, the elements influence the perception of the pedestrian with respect to the public space, helping to increase awareness on the theme of the liveability of the context.

Also with reference to the issue of cost functions applied to pedestrian mobility, it is noted that the studies are mostly focused on urban contexts. We recall, for example, the research by Virkler and Elayadath (1994) who analysed the relationship between speed and pedestrian density, and Vanumu, Ramachandra Rao, & Tiwari (2017) who systematically revised the fundamental diagrams of pedestrian flow characteristics. Other studies have proposed updates to the Levels of Service (Mori and Tsukaguchi, 1987); with reference to the type of infrastructure (Kadali and Vedagiri, 2015); or again they investigated the relationships between pedestrian traffic parameters considering different categories of users (TRB, 2010; FGSV, 2015; Gattuso, Cassone, & Malara, 2022).

3.1.2. Pedestrian routes. Excursion and tourist ways

The application of cost functions to pedestrian mobility requires specific insights, currently little treated in the literature. Before going into the details of the cost functions, it is necessary to specify the type of itinerary taken into consideration.

It is necessary to distinguish between urban, extra-urban and mixed pedestrian itineraries, using the boundary of the urban area as a criterion. The development of the itinerary within the urban or peri-urban perimeter is not only relevant from a geographical-administrative point of view, but also with respect to the characteristics of the route (for example the flooring type, since in the city the route is paved while at the extra-urban level it is mostly dirt; but also of signs, frequency of pedestrians encountered, support infrastructures present such as benches, fountains, etc.).

A second classification (Fig. 1) can be made on the basis of the duration of the pedestrian itinerary, thus distinguishing between routes lasting one day or few hours (generally defined as short excursions (hikes) and routes extending over several days (routes or trail). Then it is possible to move on to the identification of the cost functions.

This study refers to the more general case of mixed-type routes, characterized by urban and extra-urban sections, with crossing of urban boundaries, with possible stops and overnight stays in facilities dedicated to hospitality (food and lodging).

With reference to the duration, we will refer to routes lasting more than one day. This requires that accommodation costs should also be included in the analysis.

At the basis of this choice is the growing interest in new ways of travel, which fall within the so-called slow and sustainable tourism. For some years tourism experiences have been spreading based on a growing awareness on the part of travellers who are looking for new experiences, taking the field in first person, often directly engaging the five senses on a daily basis. The demand on this front is growing rapidly. On the other hand, and consequently, the offer of new types of tourist packages is promoted, influencing demand according to a "pull" method. In this way we also aim to stem the rampant phenomenon of “overtourism” and promote, on the contrary, forms of sustainable tourism.

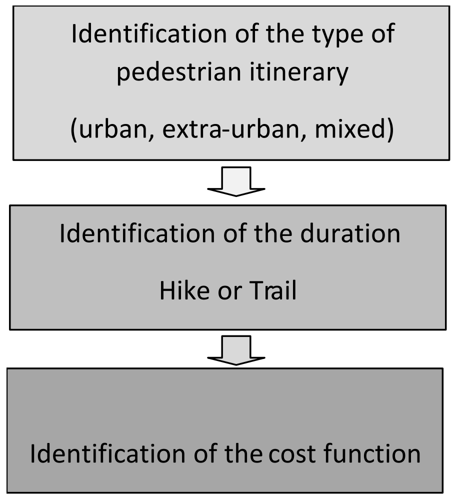

Figure 1. Specification process of the pedestrian cost function.

According to the World Tourism Organization, in 2030 the international mobility of tourists will exceed 2 billion trips, distributing themselves unevenly over specific areas of the world and at certain times of the year. This determines forms of invasion of "hit and run" tourists which do not produce significant economic and social repercussions on the localities crossed, but involve a series of problems on the areas considered; for example, in Italian cities of art often occur phenomena of degradation, crowding, traffic congestion, cultural impoverishment of the tourist destination, deterioration in the quality of life of the residents, negative environmental impacts. The response strategies on the part of the Public Authorities are different and range from gated tourism, to seasonal adjustment or, precisely, to the promotion of new types of holidays such as those based on paths and, in general, walking routes.

3.2. Cost functions for tourist pedestrian mobility on paths

A path can be qualified as an itinerary *k* composed of an ordered set of stages, such that each stage *i* is represented by a link. Generally, a stage develops over the course of a day.

The moving tourist commits time and energy, he will also have to face expenses. It is therefore possible to distinguish the time and monetary cost components.

The total time (5) involved in a stage can be assumed to be made up of the sum of two rates: walking time or distance covered by the *i* (T_{Pi}) and stopping time (T_{Si}).

$$T_i = T_{Pi} + T_{Si} \quad (5)$$

In reality these two quantities could be considered as a composition of partial times, where a stage could be broken up into sub-phases of movement (links) and rest pauses (nodes).

It could therefore be assumed:

$$T_{Pi} = \sum_x T_{Pxi} \quad (6)$$

$$T_{Si} = \sum_x T_{Sxi} \quad (7)$$

with $\mathbf{T_{Pxi}}$ travel time on section *x* of stage i (6)

and $\mathbf{T_{Sxi}}$ break at the end of section *x* on stage i (7).

According to the classic formula that links time to the distance travelled and the speed necessary to travel it, it is possible to calculate the travel time (8) by relating the distance L_i to the speed v_i:

$$T_{Pi} = L_i / v_i \quad (8)$$

The average speed (9) can be expressed (Gattuso & Gattuso, 2020) as a function of the type:

$$v_i = f(\text{user, route type, load, environment}). \quad (9)$$

In fact, different types of users can be distinguished (young and expert, young but not expert or sporty, child or elderly, stroller) but this does not exclude the possibility of including subjects with specific needs in the study (pedestrians with children, people with reduced mobility, women, visually impaired or blind, etc.). The speed of travel can also vary according to the infrastructural characteristics such as: type of track (dirt, asphalt, etc.); overall steepness and gradients; safety and presence of obstacles (roots, sand, crossings, fords, sharing the route with roads open to other vehicles, etc.); comfort (lighting, presence of cover with trees, presence of water sources, etc.) ease of orientation (absent signs, GPS tracks, symbolic signs). The load conditions of the individuals (light or heavy backpacks) also affect the average speed; as well as the contingent environmental conditions such as altitude, season, weather parameters (temperature, humidity, wind, rain).

In the modelling practice of urban areas, the average speed of an ordinary walker is assumed to be equal to *3.6 km/h (1 m/s)*, but in reality different values could be assumed in relation to the factors mentioned above; in the field of out-of-town hiking there are different methods for estimating specific average speeds, from the criterion based on experience to the so-called Swiss Method or even the Brazilian Method. A trained hiker can proceed at a pace of about *3.5-4.0 km/h* on a flat or undulating path; but the speed changes uphill and downhill or at altitudes above *2800-3000* m above sea level.

The stopping time T_{Si} is also variable and depends on both the type of excursion and the users; for example, pedestrians more interested in physical and sporting performance will reduce stopping times; on the contrary, knowledgeable hikers will be more interested in the places crossed, in the panoramas, in the culture and in visiting the so-called Points of Interest (POI), so much so that the stopping time can assume an importance comparable to the walking time.

The time relating to an itinerary *K* (10) will be given by the sum of the times relating to the branches (stages) belonging to the route itself; denoting with I_K the set of branches belonging to path *K*:

$$\mathbf{T_k} = \sum_{\mathbf{i}} \mathbf{T_i} \quad \text{with } \mathbf{i} \in \mathbf{I_K} \quad (10)$$

It could also be useful to separate the two components, travel time (11) and stopping time (12), for the journey in order to analyse them individually:

$$\mathbf{T_{Pk}} = \sum_{\mathbf{i}} \mathbf{T_{Pi}} \quad \text{with } \mathbf{i} \in \mathbf{I_K} \quad (11)$$

$$\mathbf{T_{Sk}} = \sum_{\mathbf{i}} \mathbf{T_{Si}} \quad \text{with } \mathbf{i} \in \mathbf{I_K} \quad (12)$$

In addition to the time costs, it is possible to consider costs of a monetary nature.

The monetary cost (13) for a generic user referring to the itinerary K can be expressed as:

$$C_K = C_g + C_v + C_p \quad (13)$$

with C_g cost for guide services, C_v cost of food, C_p cost for accommodation facilities. For organized trips, generally these costs refer only to the route and not to the component stages.

The generalized cost function (CG_K) related to the whole journey takes into account both cost components, time and money (14):

$$CG_K = C_K + \alpha\, T_K \quad (14)$$

where the parameter α represents the time replacement rate in monetary units.

Generally, in the context of urban modelling, with trips for professional reasons, in Italy, this parameter assumes a value of around *8-12 euros/h*. In the case of mobility on excursion routes, the value of α could be very low or even zero, this because in such cases the travel time is not perceived as an impedance/sacrifice, but as an advantage, a utility inherent in the reason for the travel.

Or even, depending on the user groups, we could have:

$$CG_K = C_K + \alpha\, T_{Pk} + \boldsymbol{\beta} \mathbf{T_{Sk}} \quad (15)$$

If the group is made up of sportsmen, it could be verified that the α parameter is modest and that the β parameter has a consistent value, since the stopping time represents an unwanted impedance. Conversely, if the group is made up of aware hikers not interested in simple physical performance, we could assume both α and β to be null; or again, a negative value for β is equivalent to considering the stopping time (for example to admire a panorama or a historic site, or to enjoy the scent of an aromatic plant) not as a cost, but as a benefit (15).

The modelling approach based on cost (or utility) functions offers a series of advantages since it allows the analysis of the mobility supply/demand interaction, but also the possibility of comparing two or more itineraries, in order to measure the degree of difficulty of a route, in quantitative terms. The availability of significant models, i.e. calibrated and validated cost functions, makes it possible to use valid tools in the planning phase, as a decision support tool, in order to direct the project choice along some paths compared to others with worse from an economic-organisational point of view; and in the design phase, to adjust the routes in relation to the type of expected users.

4. From the cost function to the model

The definition of the model, in addition to the specification phase (identification of the variables involved and expression of the functional form), includes two other fundamental phases: the evaluation of the parameters associated with the independent variables (calibration) and the validation phase. At present time the research is oriented towards these activities which requires targeted investigations in the field and an appropriate Data Base useful for statistical operations (Fig.2).

The cost function of pedestrian mobility on tourist routes must be translated into models calibrated in relation to the application context (city tour, rural excursion, walk in mountain areas, etc.). First of all, it is necessary to calibrate the parameters of the individual models through field surveys and statistical analysis techniques applied to the data acquired through observations. The validation phase consists in comparing the results deriving from the application of the model with real data, or coming from new observations; specific tests will be used in order to verify if the model is capable of reproducing the choices made in the real context. The conclusion of the process will allow to attribute values to the parameters α and β for each type of prefigured model.

Fundamental for the calibration and modelling validation phases is the realization of a field survey. The investigation process can be divided into five phases: planning, designing, carrying out the investigation; preparation and management of the collected data; data analysis through a series of statistical indicators. It is generally preferred to seek basic information through field measurements and questionnaires proposed to a sample of representative users. Field measurements can, for example, be aimed at detecting the average speed of travel on routes with different characteristics and for different users.

With reference to the objectives of the questionnaire, the attention will instead be directed to the analysis of user behaviour and to the evaluation of their perception of some variables such as the monetary cost, travel time, parking time, or other preference variables with respect to the sites visited (users' perception of non-physically measurable characteristics).

Therefore, the survey can be structured on two levels: on the one hand, a sub-survey based on observations, similar to what was already done for the urban level in the 2022 study (Gattuso, Cassone, & Malara, 2022); on the other, the compilation of questionnaire forms, to attribute, for example, a VoT associated with the time components for homogeneous classes of tourists. In order to collect responses from different types of users, it is convenient to use a graduated scale, in order to avoid the dispersion of data typical of open-ended questionnaires; it will also be advisable to avoid an excessive number of questions.

Naturally, the investigation will also be extended to pre-existing literature studies where similarities of purpose and approach are recognised.

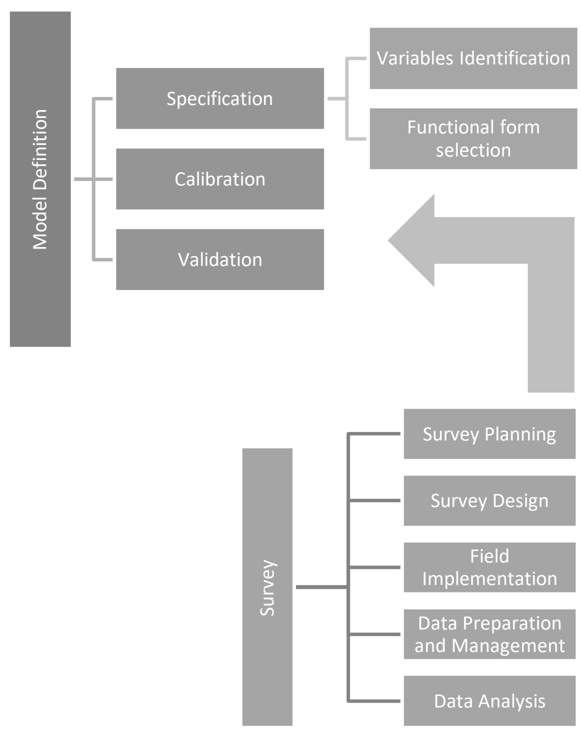

Figure 2. Methodological approach for survey and for model definition.

The results of the surveys will be aggregated and composed in a structured database. The judicious preparation of the database will facilitate the reading of the phenomena of interest and the subsequent statistical analyses.

5. Results and discussion

Active mobility (pedestrian and cycling) is attracting growing interest in the context of institutional reflection and research on sustainable mobility. The in-depth analysis from an engineering point of view relating to pedestrian infrastructures and pedestrian mobility behaviours will allow us to address the issue according to a scientific approach and obtain a clear and objective reading framework of the field of interest both with reference to urban pedestrian mobility and the extra-urban one, even if the second has often been placed subordinate to the first. The "sprawl" phenomenon has had a negative impact on the possibility of walking on medium-long urban routes, often characterized by a polarization between the centre and the periphery, and on infrastructures designed to favour the outflow of vehicles. This has meant that attention is focused above all on the development of urban infrastructures in support of active mobility: from the 30 zones to cycle paths, from "15-minute" cities to greenways.

Therefore, research on extra-urban or mixed routes is still underdeveloped. Only in recent years, also due to the need to deal with the issue of overtourism, attention has been shifting towards the latter. Just think of the issue of planning new walks and trails, an expanding phenomenon in the last twenty years, or of the great cultural itineraries, some entirely developed along mixed pedestrian routes (urban and extra-urban), such as the Camino de Santiago and the Via Francigena. Many new pedestrian, excursion-tourist routes are being created, sometimes on spontaneous initiatives by groups of enthusiasts, sometimes financed by government authorities, such as those aimed at linking territories that share the presence of Unesco sites with pedestrian or cycle paths.

As mentioned, after the phase of identifying the cost functions relating to pedestrian paths of the hiking type, it will be necessary to complete the model with the calibration and validation phases, to be completed by carrying out a specific survey. The model constitutes a simplified representation of the system; in this case pedestrian mobility on hiking itineraries. It is evident that this model must be sufficiently similar to the functional nature of the real system but devoid of its complexity and, therefore, simple to manage. The simulation of pedestrian mobility on hiking itineraries, i.e. will allow to verify the goodness of the model under certain conditions.

Modelling of pedestrian excursion itineraries and subsequent simulation of the same will allow, among other things, to verify the adequacy of existing or potential infrastructures; analyse and optimize current infrastructure; support institutions in the decision-making phase; measure and plan any innovations; integrate pedestrian mobility with other types of movement.

The deepening of the studies on pedestrian mobility, with modelling and simulation, will also make it possible to support institutional decision-makers in their planning and programming choices regarding excursion routes, especially with predictive elements that allow them to select upstream the creation or financial support of the routes considered most suitable interest for the needs of potential and differentiated users, and for community.

6. Conclusions

This work has allowed to consolidate a first phase of research aimed at building specific models for evaluating the cost or utility of trails. The proposed approach is limited to the first phase of model definition (specification). In this phase, a definition was made of the general cost function associated with a pedestrian path, up to specifying its (additional) form and attention was then focused on a methodological approach to be followed to come to the identification of specific models, through field investigations, parameters calibration and statistical validation. The advantage of this approach is that it can also be generalized to other contexts such as urban or mixed urban/rural. It will therefore be essential to carry out an investigation aimed at the subsequent steps (calibration and validation). The growing interest of tourists in cultural pedestrian itineraries and the attention of the institutions towards the financing of new projects of pedestrian itineraries on extra-urban or mixed routes, direct research towards models aimed at qualifying pedestrian itineraries for excursions, with their differences and peculiarities.

The models will make it possible to analyse and compare alternative plan and design solutions for pedestrian routes, proposing themselves as decision support tools in technical and programmatic terms, in order to configure a supply of differentiated routes but responding to the needs of different user groups in terms of physical characteristics, travel motivation, usage behaviour.

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