



Urban Accessibility to Healthcare Facilities for the Elderly: Evolution of the Time-Based 2SFCA Methodology for the Nice Case Study (France)

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Abstract. This study proposes a GIS-based methodology to measure accessibility to urban services, from the elderly perspective to support urban planning processes. In the light of a significant demographic change, policymakers should promote age-friendly urban planning approaches in order to guarantee equal opportunities to access to services and activities. We developed a methodology to measure accessibility to healthcare provision services, which considers urban characteristics and mobility features, as well as behavioral traits of older adults. The method belongs to the family of 2SFCA (Two-Steps Floating Catchment Area), which evaluates accessibility as the combination of both supply and demand of urban services; thus, we introduce innovative elements to shape actual mobility opportunities for the elderly and their travel choices within three different timeslots. The methodology was applied to the city of Nice (France), to measure accessibility to proximity services managed by Healthcare Regional Agency (l'Agence Régionale de Santé – ARS) of Provence, Alpes and Côte d'Azur. The outputs allow to quantify elderly people accessibility to primary health services and the application to the French case study has shown that the methodology could be effective to identify critical issues to support urban planning process.

Keywords: Urban accessibility · Elderly · Proximity healthcare facilities · GIS

1 Introduction

In Europe the share and number of older people will increase. The proportion of population aged 65 and over is expected to increase to 30.3% by 2070, compared to 20.3% in 2019, and 13.2% is projected to be aged 80 years or older, compared to 5.8% in 2019 [1]. Although Europe is by no means the only continent with an ageing population, the process is most advanced here. It is driven by a significant increase in life expectancy and lower birth rates, which is affecting EU countries in a variety of ways. For instance,

in 2018, life expectancy at birth increased to 78.2 years for men and 83.7 for women and this growth is projected to continue: men born in 2070 are expected to live 86 years, and women 90 [2]. Hence, on average, Europeans will enjoy longer lives.

This trend is having a significant impact on people's everyday lives and on our societies. It has implications for economic growth, fiscal sustainability, health and long-term care, well-being and social cohesion [3, 4]. Thus, the Covid-19 pandemic has disproportionately impacted on older people – in terms of hospitalizations and deaths – and it has highlighted some of the vulnerabilities, and consequent challenges, that an ageing population poses on health and social care. Moreover, social isolation, loneliness, and depression due to age-associated limitations may affect the opportunities that can potentially arise within 'silver' age: elderly people are fundamental resources for their families and for the communities in which they live [5].

Healthy and active ageing is a personal choice and responsibility, but it depends heavily on the environment in which people live and public policies can play a significant supporting role [6]. Along with an increasing interest, age-friendly urban planning interventions have emerged as an urgent need on national, regional and local agendas. Within these issues, living near services has been shown to be important for older adults in performing activities to meet daily needs, including access to food shopping, healthcare provision, public transportation, banking, social and sportive clubs [7, 8]. As essential service within the supply of urban areas, healthcare facilities may play a key role to ensure a good level of spatial equity and quality of life for the elderly [9]. These issues span multiple fields: social sciences, urban and regional planning, transport planning, health geography, information and communication technologies (ICTs) [10].

The evaluation of accessibility to essential services provides a spatial analytical perspective to assess whether or not, and to what degree, the distribution of urban public facilities is equitable [11]. Accessibility measures reflect the potential availability of healthcare facilities, if based on solid theoretical ground, by revealing the ability of different people to overcome spatial, physical, temporal and socioeconomic barriers to healthcare provision [12, 13].

Studies over the past two decades have provided significant development for measuring spatial accessibility to public services. The two-step floating catchment area (2SFCA) method, based in GIS (Geographical Information System) environment, is the most widely applied measure of spatial accessibility due to its operability [14]. A growing body of cross-sectional research has enhanced and improved the theoretical foundation and applicability of 2SFCA. Although many researchers have provided several gateways to the accessibility paradigm, there has been no reasonable mechanism to integrate results of urban public facility measures into an overall evaluation scheme suitable for easy and intuitive use by planners. Moreover, far too little attention has been paid to develop methodologies that should be easily applied and interpreted to heterogeneous urban contexts.

This paper traces the development of an enhanced 2SFCA method to evaluate accessibility to healthcare facilities and provides the results of its application to Nice, France. This work is part of a wider research project, whose partners are the Department of Civil, Building and Environmental Engineering at University of Naples Federico II (Naples, Italy), the research laboratory UMR ESPACE at Université Côte d'Azur (Nice, France)

and Energent S.p.A. (Rome, Italy), that aims at providing a decision-making support tool for facing elderly people's needs in ordinary conditions as well as other operating scenarios. Hence, the primary aims of this paper are: (i) to apply and, hence, validate the methodology for a case study in Nice, France; (ii) to demonstrate that results can be translated into takeaways for practice, according to a holistic approach.

This paper has been divided into five paragraphs. Following this introduction, we present a literature review, in order to highlight how the accessibility paradigm has evolved in urban planning, how it has been introduced in assessment methodologies and, finally, which are the main traits of research design. The third paragraph focuses on the proposed method. Following, the results of the application to the city of Nice are discussed. In the final paragraph the key features of the methodology evolutions, according to the results of its applications to Naples, Milan (Italy) and Nice (France), and the conclusions of the work are presented.

2 Literature Review

Ensuring good health and promoting well-being are among the sustainable development goals of the United Nations Agenda 2030 program [15]. Hence, equal accessibility to healthcare is recognized as a universal key for improving quality of life and should drive decision-making processes for urban and transport planners, as well as for healthcare providers [16, 17]. Due to the increasing political and scientific interest on the topic, several methods and approaches were produced to determine healthcare accessibility at different levels. At the same time, since geographical analyses of spatial equity rely on different measures, the conceptualization of accessibility is a key issue to understand their results and sensitivity [18, 19].

The earliest studies of the topic defined accessibility as the count of facilities within a geographical unit. Thus, spatial accessibility also refers to the relative ease by which people can reach the locations of facilities and activities, from a given location. This approach implicitly considers factors such as spatial externalities, physical and natural barriers, the structure of transport network, the frictional effect of distance, properties of the supply side, safety and socioeconomic issues [20]. According to this approach, in our research, we understand accessibility as an inherent feature of urban environment, which may explain the competitiveness and social justice of a territorial unit, compared to another.

Thanks to the availability of reliable big data and the processing capabilities of GIS-based technologies, researchers are developing advanced quantitative methods and procedures to evaluate accessibility to urban services, according to this holistic approach. However, there have been very few reasonable mechanisms to integrate academic results of urban public services measure into an overall evaluation scheme, suitable for intuitive and easy use by planners [21, 22].

The simplest way to assess healthcare accessibility is to use contour measures (or opportunity measures), which define catchment areas by drawing one or more travel time contours around a node of interest and measuring the number of opportunities (facilities, services and activities) within each contour. This measure is easy to compute and understand, but suffers of a poor theoretical basis, since it is not possible to weight different

distances within the same area in evaluating accessibility. Moreover, in a metropolis where many alternatives exist the distance to the nearest primary care service does not match the people's demand.

In order to define catchment areas by measuring travel impediment on a continuous scale, gravity measures were introduced: even though they are more accurate representations of travel resistance than contour measures, they tend to be less readable and neglect the variation across individuals living in the same area [23]. The Two-Steps Floating Catchment Area (2SFCA) is among the most widely used gravity-based methodologies to evaluate accessibility. In order to fill the gap between scientific theories and real practices, it takes into account the main urban, individual and mobility variables within a user-friendly procedure. It is a special application of a gravity model and it was proposed for the first time by Luo and Wang in 2003 [24]. From its first application, the method has been further developed and enhanced. Scientific literature proposes many examples of 2SFCA application to evaluate accessibility to services at different territorial scales and according to different social and age perspectives. For instance, researchers investigated spatial accessibility to urban public facilities, such as parks [25, 26], physicians [27], compulsory schools [28], but also to rural green areas [29], hospitals [30–32] and eldercare centers [25]. The latter facilities tend to have larger service areas, crossing the administrative boundaries of a city or a region. Hence, when designing 2SFCA methods researchers have to answer preliminary questions: the first refers to the demand point (population) of public facilities, which usually is the smallest census area. The smaller the research unit, the more detailed accessibility differences can be obtained. The second question concerns the extent of study area, which has to take into account several issues: firstly, the actual catchment area size of the service and its temporal modification, between weekdays and holydays, or throughout the day; secondly, in order to support decision-making processes with reliable academic findings, the study area should match the administrative domain of policymakers and involved stakeholders (e.g., transport companies and healthcare providers).

Our work aims at contributing to both methodological and practical terms within the debate of urban accessibility. Hence, we answered the previous questions with an enhanced research design, in order to evaluate spatial and temporal accessibility to proximity healthcare services, from the elderly perspective, and systematically consider features from both supply and demand sides.

3 Research Design

We propose an enhanced method to evaluate accessibility to urban services and facilities, and to point out spatial and temporal inequalities among elderly population. This paragraph summarizes the newest advancement of a wider research project, whose aim is to develop an operational methodology to support decision-making processes in order to turn cities into *age-friendly* environments [33]. As highlighted in the previous paragraph, the methodology has been designed and applied in a GIS environment to take advantage of its storing, analyzing, and visualizing capabilities. What we are describing now is the third phase of a wider research design: starting from a methodological hypothesis, we enhanced and modified it through consecutive validation steps, by applying the methodology to heterogeneous case studies. We measured accessibility to primary healthcare

facilities from the elderly perspective for Naples, Milan (Italy) and Nice (France), which differ from each other for territorial and orographic contexts, socioeconomic issues and administrative rules. Moreover, while designing the methodology, we considered the availability of open and reliable data as a key issue, in order to turn the results of our research into real-world practices.

At the same time, we paid attention to the theoretical bases of the methodology that takes cue from the 2SFCA procedure, described in previous paragraph. The method developed by Luo and Wang in 2003 only represents the starting point of our research. In fact, it was enhanced with additional variables and steps to address the actual mobility capital for people aged 65 and over and improved following the findings of each case study application [34, 35].

As concerns the components of urban and mobility systems, both supply and demand-side features were considered, since the level of accessibility in an urban environment depends on the interactions between supply and demand. In particular, the demand for healthcare provisions consists of population distribution P_i , where i refers to the smallest territorial unit, a 50-m-side hexagonal cell [36, 37]. The use of hexagonal grid (rather than a square one or census tract) is preferred when dealing with problems related to the connectivity of different space units and identifying shorter paths for calculating travel distances [38]. Due to geometric issues, the hexagonal grid provides a substantially better match between distances measured in grid units and straight line (Euclidean) distances, which might make a coarse hexagonal grid more acceptable for modelling dispersal than a square or rectangular grid. Another advantage of the hexagonal grid is its greater clarity when used for visualization.

On the supply-side, the land-use component is described by the combination of healthcare structures (j) locations and their resources – S_j – described, for instance, by the number of working physicians, available beds or surface of buildings (m^2).

In order to include features on the supply-side of transport facilities, we developed a multimodal network to run time travel analyses. The network is made of walkable roads and transit (bus and metro) lines. The residential locations of dwellers, approximated to the barycenter of hexagonal cells – i – were considered as origins of multimodal travel journeys to reach healthcare facilities.

The most innovative aspect of the developed study is the introduction of variables and feature that take into account the behaviors of the elderly population, such as their dependence on public transport and their reduced use of private cars. In other words, the study introduced characteristics linked to the behavior of the population, considering them essential to improve accessibility to places and services of the urban system.

We introduced Gaussian distance-decay functions – $W_{i,j}$ – [39], one per age group, in order to consider the degressive mobility capital of elderly people while ageing. Moreover, we attributed decreasing walking speeds by age group (65–69; 70–74; ≥ 75) to the links of pedestrian network, to measure travel time $t_{i,j}$ to get from origins i to healthcare facilities j . The computation of travel time is the second innovative feature of the methodology: in order to evaluate travel times from each hexagonal cell to the main local health buildings, we created a multimodal transport network. We considered

the network as the combination of both walkable streets and local public transport lines (bus and metro) in order to better simulate elderly mobility habits.

$$W_{ij} = e^{-t_{ij}^2/\beta} \quad (1)$$

According to Lindemann *et al.* [40] and Rydwick *et al.* [41], we introduced decreasing walking speed for each age group: 0.8 m/s for those aged 65–69; 0.7 m/s for people aged between 70–74; 0.6 m/s for the oldest (≥ 75). As far as for the Gaussian distance-decay functions, their main characteristic is that they quickly decrease when time travel increases and gets close to the maximum time that each elderly age category manages to hold (according to their physical capabilities) to access health services. Moreover, as people age, their mobility capital decreases; hence, the inverse of impedance coefficients β were set equal to 180 for people aged between 65–69, 160 for those between 70–74 and 140 for those aged 75 and over, to best represent mobility attitudes of different elderly age categories according to outcomes in the scientific literature [42]. The last component relates to the variable accessibility perceived by dwellers due to temporal issues. The transport network model is based on GTFS (General Transit Feed Specification) data to run separate temporal analyses and evaluate accessibility variations during a weekday. The input data described above are essential features to process the method, which consists of two consecutive steps, described by the following formulas.

$$R_j = \frac{S_j \cdot \left(\frac{S_j}{S}\right)}{\sum_{65-69} P_i \cdot W_{ij}^{65-69} + \sum_{70-74} P_i \cdot W_{ij}^{70-74} + \sum_{>75} P_i \cdot W_{ij}^{>75}} \quad (2)$$

$$A_i = \sum_{65-69} R_j \cdot W_{ij}^{65-69} + \sum_{70-74} R_j \cdot W_{ij}^{70-74} + \sum_{>75} R_j \cdot W_{ij}^{>75} \quad (3)$$

R_j is the supply-demand ratio of each healthcare structure, while A_i refers to the overall accessibility to each i hexagonal cell's primary healthcare provision. For the representation of results by the GIS in maps and tables, the proposed method implements a quantile classification of measured accessibility in ten levels, from level 1 (low accessibility) to level 10 (high accessibility). The quantile classification is defined as cumulated accessibility values considering the three age categories [43].

4 The Case Study

Nice is the fifth French city for number of inhabitants (over 340,000) and population density of 4.762 inh./Km² (INSEE, 2017). The city is close to the France-Italian border, 20 km away the Monaco Principality. The city stretches from the sea to the Alpes, with a 71.92 Km² surface, and 520 m total ascent. It is divided into nine urban administrative districts, which are named cantons. The share of elderly people in Nice, in the 2017, is over 24% (48,102 women and 32,819 men). Table 1 shows the distribution of elderly people in the nine city cantons, and Fig. 1 displays in detail the localization of the elderly. The highest shares of people aged 65 and over live in T2, T4, T6, T5 and T9 cantons.

Like other European Welfare States, France provides to citizens a system of universal health care, which is largely financed by the government through a system of national

Table 1. Elderly people distribution and primary health center in the city districts of Nice.

Districts	Number of Primary health center			
	Elderly	Morning	Afternoon	Evening
T1 - Plaine du Var	6,823	2	2	0
T2 - Ouest Littoral & Coteaux	12,100	1	0	0
T3 - Collines niçoises	9,159	2	2	1
T4 - Centre Ouest	11,045	3	3	0
T5 - Centre Nord	10,081	3	3	0
T6 - Centre Est Trois Collines	10,254	4	4	1
T7 - Rives du Paillon	4,824	0	0	0
T8 - Coeur de Paillon	6,550	3	3	0
T9 - Est Littoral	10,085	2	2	1
	80,921	20	19	3

health insurance. However, there are some major differences in the structure of the French healthcare system and in its financing, versus its EU peers. Most crucially, France spends over 11% of GDP on health care, much higher than the EU average. The French healthcare provision is based on a Social Security system, which is available to all and comprises a fully integrated and capillary network of public hospitals, private clinics, doctors and other health professionals. It is a multi-payer system which provides medical care for all citizens regardless of age, income or social status.

In a recent document published by the French Ministry of Healthcare and Solidarity, it turns out that 99,9% of French citizens access to a physician within 20 min. At the same time, the ministry highlights that, because of healthcare supply distribution, it fails to meet the demand for care, in some territories. The Healthcare Regional Agency (l'Agence régionale de santé – ARS) of Provence, Alpes and Côte d'Azur developed in 2018 a regional strategy to strengthen and assure equal accessibility to territorial services, through the Territorial Plan of Accessibility (PTAS – Plan Territorial d'Accès aux Soins). The plan is mostly focused on the increasing share of people aged 65 and over, promoting higher accessibility to proximity healthcare facilities, in particular to polyclinic centers (Maisons de Santé Pluriprofessionnelles, Centre de Santé and Communauté Professionnelle Territoriale de Santé).

The healthcare system of such services for the city of Nice and dedicated to elderly people is made of 20 facilities. They were selected from France OpenData database (2021). Each center offers a variable number of primary health services, from 10 to 1. The data of health services located in each structure was collect consulting the open-access information available on the websites. Also, the opening hours are different for each center, and this feature was taken into account to assess temporal variation of accessibility, within a weekday. Table 1 compares the number of open centers for each timeslot in the districts. For this application, we consider only the public primary health centers located in the city of Nice.

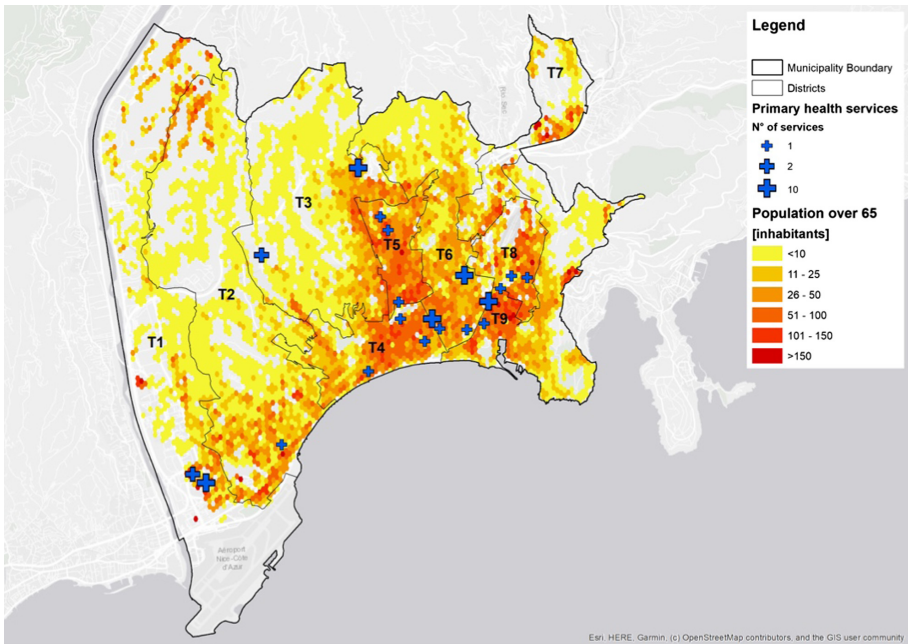


Fig. 1. The elderly people location in the city of Nice.

For the mobility component, we created a multimodal network of Nice, using ArcGIS tools to connect the walking roads network and GTFS (General Transit Feed Specification) data into a network dataset and to evaluate the total travel times. First, OpenStreetMap data was used to create the walking network, taking into account only pedestrian roads and their slope. For this application, we consider the pedestrian network's slope because it is a significant aspect in Nice that influences the readiness to walk, especially for the elderly people. Then, GTFS data of 2020 from the Transit Company of Nice (Lignes d'Azur) were used to add bus and tram lines and stops in the local transport network. Since public transport is not a continuous service in space and time, additional modelling operations were needed to join the pedestrian system to the public transit system (Fig. 2). Once the multimodal network was ready, the ArcGIS Network Analyst tool was used to compute an OD (Origin and Destination) matrix, showing the total travel time to get from a generic hexagonal cell to the city healthcare centers.

For the application to the city of Nice, we evaluated the level of urban accessibility to 20 ambulatories that serve over 80,000 old people in three different timeslots (Morning, Afternoon and Evening). The available health services of each healthcare center were addressed as the number of surgeons of interest to the elderly, that are: cardiology, dentistry, urology, otolaryngology, ophthalmology, dermatology, orthopedics, pulmonology, diabetology, rehabilitation, neurology.

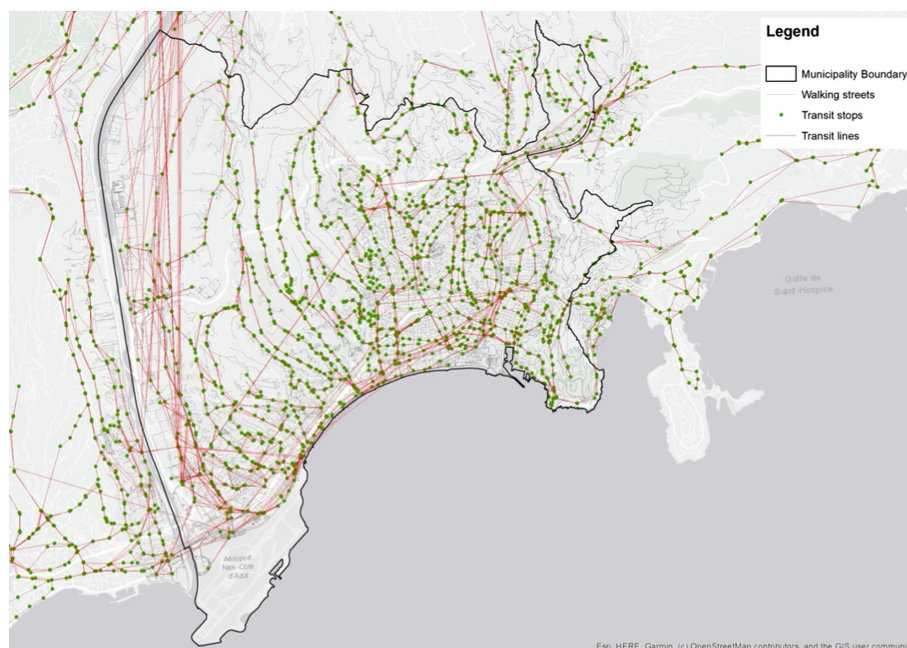


Fig. 2. The walking and transit network in the city of Nice.

5 Results and Discussion

In this paragraph, we present the outcomes of EM2SFCA methodology application in the city of Nice. We considered three different age groups (young elderly, medium elderly and old elderly) and three timeslots (morning, afternoon and evening). Figure 3 presents the results of evaluating the total accessibility for elderly people at primary health services in the selected city for the three-time scenarios. According to scientifically established and widespread practices (PTAL – Transport for London), ten accessibility levels' thresholds were chosen through a quantile classification. These accessibility values are represented in ten classes following a color gradient from the red (very poor accessibility) to the green (very good accessibility). The primary health services are added to the three different maps in Fig. 3 following their opening and closing timetables. As morning time, we considered 6 am to 12 pm, afternoon time from 12 pm to 6 pm, and evening time after 6 pm. Hence, the GIS analyses were run for a 9 am scenario, 4 pm and 8 pm scenarios.

In the three maps in Fig. 3, we can easily recognize some specific spatial patterns. The historical center of Nice always shows a good accessibility during the day (characterized by green color independently by the timeslot). In the morning and afternoon also the two main valleys in Nice are show a high accessibility towards the primary health services: the one in the middle with the Magnan river and the one on the west with the Var river. The hills of Nice are permanently characterized by lower values of accessibility

to the primary health services, due to the distinctive street network configuration and the difficulty for the public transport system to serve all low-density subdivisions on the separate hills.

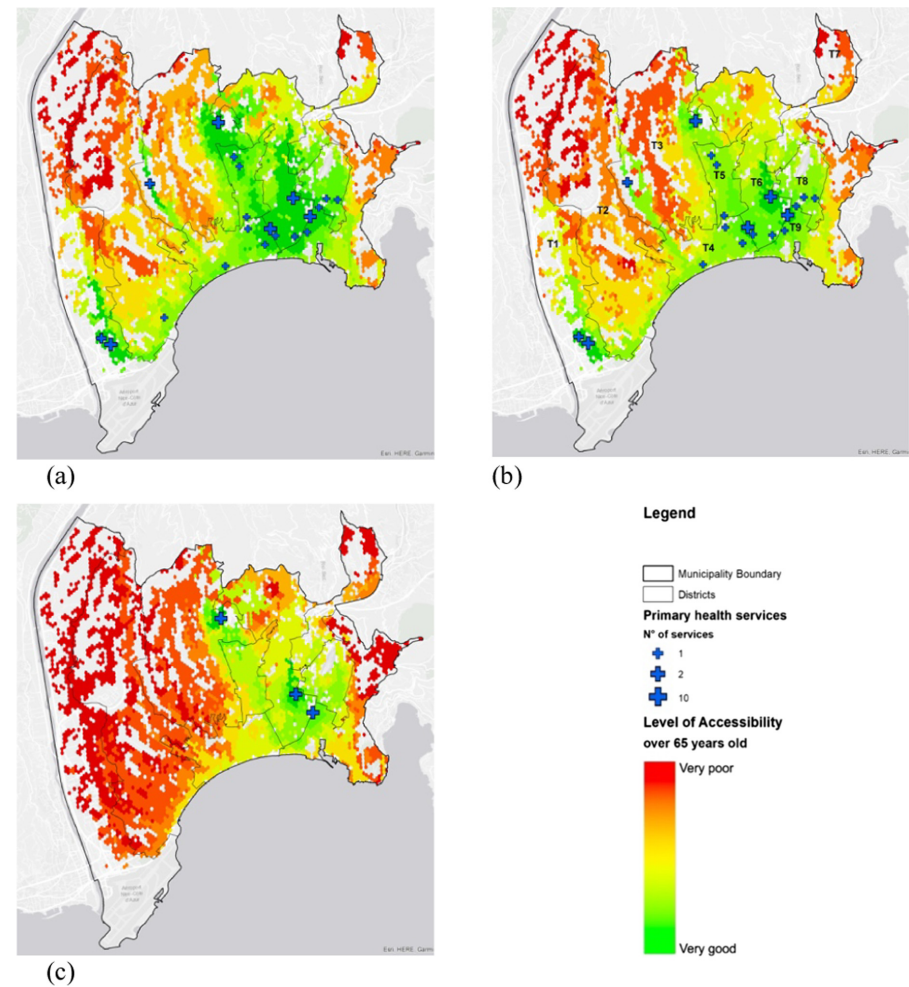


Fig. 3. The level of accessibility at primary health services in the city of Nice in the morning scenario (a), in the afternoon scenario (b) and in the evening scenario (c).

Figure 4 shows the comparison between the three-time scenarios (morning, afternoon and evening) in the city of Nice. The frequency of each one of the ten accessibility levels is represented in a proportional stacked bar histogram. In the morning time, the first five worst classes (from red to yellow) correspond only to 20% of the total values, which augment to 30% in the afternoon and to 70% in the evening. It is interesting to note that the worst class do not increase significantly during the day: The travel time to join an open service increase, but nevertheless this one remains accessible.

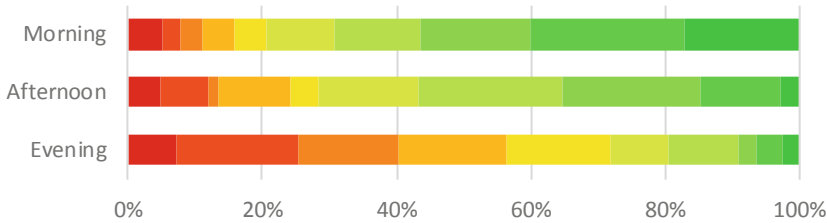


Fig. 4. The comparison of accessibility at primary health services for the elderly in the city of Nice for the three-time scenarios.

Figures 5, 6 and 7 show the variation of accessibility levels in each urban district of Nice in the morning, afternoon and evening scenarios.

For the morning scenario, the districts which have a high share of elderly people that live in the low accessibility level areas are T1 (Plaine du Var) and T2 (Ouest Littoral & Coteaux). The District T8 (Coeur de Paillon), T5 (Centre Nord) and T4 (Centre Ouest) have an adequate level of accessibility. In the afternoon scenario, there is a general reduction of the level of accessibility in each district that was influenced mostly by a poorer supply of public transport services, because only one proximity health service center closed within the afternoon timeslot.

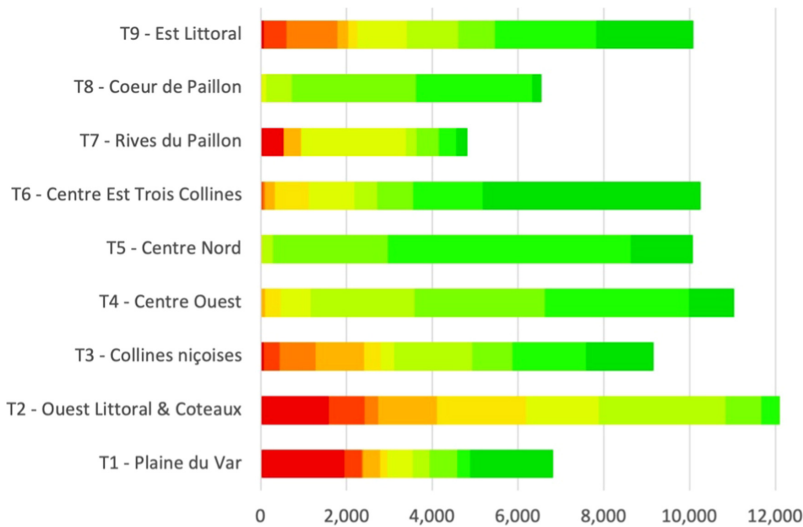


Fig. 5. The levels of accessibility for the three elderly categories in the morning scenario for the city of Nice.

There is a diffuse reduction of perceived accessibility, due to a reduced provision of healthcare services during the evening timeslot: the number of available centers is only three.

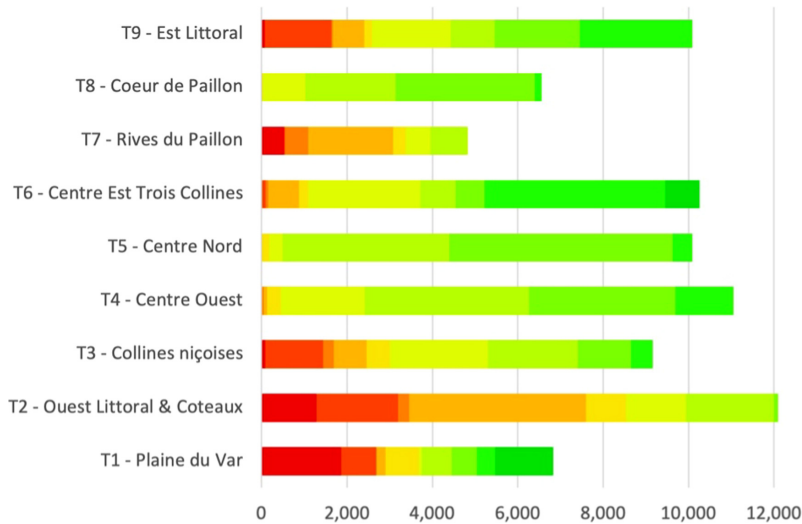


Fig. 6. The levels of accessibility for the three elderly categories in the afternoon scenario for the city of Nice.

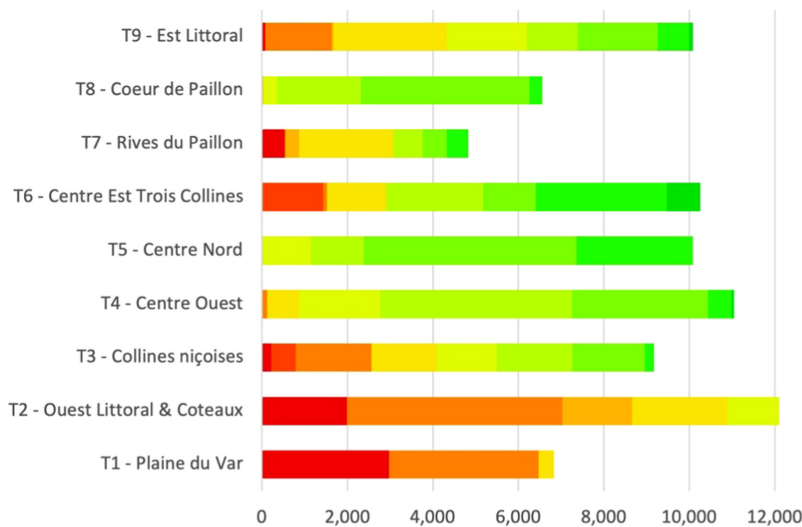


Fig. 7. The levels of accessibility for the three elderly categories in the evening scenario for the city of Nice.

6 Conclusion

In the last decades, the growth of elderly people in industrialized nations and in urban areas increased the needs for specific services for this group of inhabitants. So, the

proximity services need to be properly designed: structures' locations, the types of services, the transport system supply and the urban morphology are some of the main features influencing users' accessibility to urban services. This study developed a GIS-based 2SFCA methodology that considers urban features, both from the supply and demand side. Hence, the proposed measure for evaluating urban accessibility considers the balance between needs and resources of the urban environment. Moreover, since the methodology was designed to assess urban accessibility from the elderly perspective, we consider this age category's limited mobility capital. The present methodology provides an innovative comprehensive assessment of accessibility in urban environment, from the elderly perspective. In particular, it adds innovative and practical takeaways to the growing body of literature on the topic. From the methodological point of view, the current study employs variable distance-decay functions, walking speeds and the combination of pedestrian and transit networks to assess elderly mobility capital.

The application of the methodology to Nice may be affected by some limits due the lack of available and more recent data, concerning transport and healthcare provision features. Hence, the results refer to the measured accessibility only to a share of a wider healthcare provision system, in particular to proximity facilities which are the focus of ARS for the elderly dwelling in Provence, Alpes and Cote d'Azur Region. At the same time, the results show the effectiveness of the methodology to evaluate spatial and temporal inequalities when assessing to healthcare facilities, providing a state-of-the-art condition for decision-makers and involved stakeholders.

The case-study approach was adopted to allow a deeper insight into the enhanced 2SFCA methodology. The first application to Naples [34] highlighted how the healthcare management by local authorities may be a key issue to improve accessibility within urban environment. The second application to Milan [35] showed how almost zero altimetric differences and the combination of public and private healthcare facilities improve the overall accessibility of the city. Moreover, the Milan application was run for an ordinary and an emergency scenario, due to the outbreak of Covid-19 infection and consequent restrictions. Hence, it has proved the effectiveness of the methodology to support decision-makers in urban planning practices in ordinary as well as in emergency scenarios.

Further development of the methodology would allow not only to evaluate accessibility to essential urban services from the elderly perspective, but also to identify possible intervention scenarios, within the action domain of policymakers and stakeholders. The evolution process of the methodology, throughout the applications of three representative case studies, is allowing us to define the administrative and territorial limits of that domain of intervention, in order to build an innovative and efficient accessibility-oriented tool, to support policymakers' decisions and finally fill the hiatus between real-world practices and academic knowledge.

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