The Challenges of Demographic Transition. Network Analysis to Assess Spatial Accessibility to the Emergency Health System

Mara Ladu(✉) and Ginevra Balletto

DICAAR - Department of Civil, Environmental Engineering and Architecture, University of Cagliari, Cagliari, Italy
{mara.ladu,balletto}@unica.it

Abstract. The demography in Europe is in a stagnant phase, correlated to low fertility and mortality rates, typical of a modern and economically advanced society. Italy is one of the European countries with the oldest population, recording the highest median age of the population in 2022 (48 years). The "silver economy", i.e. the consumer economy that characterizes the population of 50–65-year-olds, up to the over 65s, needs specific services. In this sense, progressive demographic changes also require a renewed public governance, especially in terms of spatial accessibility of the emergency health system. In this framework, the study applies Network Analysis Technique to evaluate the spatial distribution of the population – with a particular focus on the over 65 population - and the relative accessibility to the network of the health emergency services on a regional scale. The insular context of the Sardinia Region (Italy) represents an interesting case study due to the significant silver population and the related multipolar spatial distribution in the 377 municipalities, affected by peripherality and marginality issues. The manuscript, which is part of the e.INS project, provides useful information and approaches to support the construction of a regional MaaS solution to improve the accessibility to the emergency health system.

Keywords: Demographic Changes · Health System · Spatial Accessibility

1 Introduction

Population aging is the most pervasive and dominant global demographic trend of our time [1]. According to the latest World Social Report [2], people aged 65 or older worldwide is expected to more than double, from 761 million in 2021 to 1.6 billion in 2050. The EU population is also aging: the number of people aged 80 years and older has increased in all Member States in 2022 [3]. Half of the EU's population is older than 44.4 years. Italy is one of the countries with the oldest population, recording the highest median age of the population in 2022 (48 years).

According to these trends, the emergence of an inverted population pyramid will be a real challenge for human development in the future. Changing demographics will also shape urban governance, especially in terms of the provision of both social services of

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general interest and specialized urban services. As a matter of fact, the "silver economy", i.e. the consumer economy that characterizes the population of 50–65-year-olds, up to the over 65s, requires a specific system of services [4, 5]. Among these, within the strategic mission of a renewed spatial planning [6], health and welfare services represent primary services to be guaranteed, also in terms of adequate spatial accessibility [7]. This is a challenge, especially in Italy, where the issue of the peripherality of internal areas is of great importance in the scientific and political debate [8].

In this framework, the paper proposes a methodological approach to evaluate the spatial accessibility to the hospital emergency network (HEN) in the Autonomous Region of Sardinia (ARS) (Italy), selected as a case study. The study uses Network Analysis (NA) techniques to analyze the spatial distribution of the population (2023), especially of the population ages 65 and above, thus detecting the level of accessibility to the HEN by public and private means of transport.

The manuscript is part of the e.INS project, which proposes forms of sustainable mobility in the regional territory of Sardinia, also for health purposes, in line with the concept of Mobility as a Service (MaaS) [9].

The manuscript is organized as follows: Sect. 2 - Literature review - provides a description of the demographic transition model, at the international and national scale (Sect. 2.1), and introduce the main issues concerning the role of spatial accessibility in urban and regional planning in Italy (Sect. 2.2); Sect. 3 - Materials, data and methods - provides a description of the study area (Sect. 3.1), the methodology (Sect. 3.2) and the dataset (Sect. 3.3) to assess the spatial distribution of the population and, therefore, the level of accessibility to HEN in the ARS; Sect. 4 and Sect. 5 discusses respectively the main results of the study and the next steps.

2 Literature Review

2.1 Stages of the Demographic Transition

The demographic transition has long been the subject of research both in the academic field and within other public and private institutions, in support of national and/or international governance. The demographic transition represents the process of change in the demographic structure of the population, in relation to the economic, social, and cultural transformations of society [10–12], from the changes observed from the pre-industrial phase to the current fourth revolution (industry 4.0) [13–15]. The demographic transition is also closely related to health, well-being, and education policies [16, 17] and can be represented in the following five stages (Fig. 1):

Stage 1 - Preindustrial: In this phase, both birth and death rates are high, resulting in slow population growth. The high birth rate is compensated by the equally high mortality, mainly due to diseases and wars, poor hygiene, and poor nutrition. This phase is typical of significantly backward socioeconomic contexts.

Stage 2 - initial transition: There is a reduction in the mortality rate thanks to improvements in living conditions, as a result of healthcare and a balanced diet. However, the birth rate remains high, leading to rapid population growth.

Stage 3 - advanced transition: The birth rate begins to decline, following the decline in mortality. This change is often attributed to economic factors, access to education, particularly for women, and birth control. Population growth slows.

Stage 4 - post-industrial: Both birth and death rates are low, stabilizing at a population growth rate close to zero or even negative. This phase is characterized by an elderly population, with challenges linked to the support of the elderly by the working age population, which is progressively decreasing.

Stage 5 - post-transitional: Fertility rates could fall below population replacement levels, leading to a long-term decline in population if not offset by net migration. This phase is characterized by demographic challenges, such as an aging population and a declining workforce.

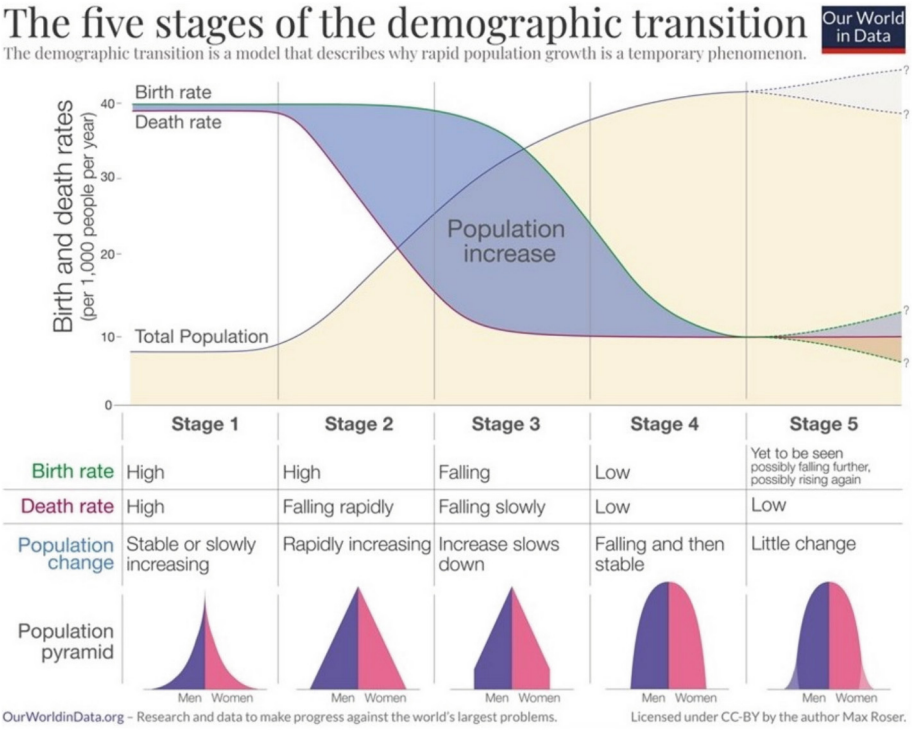


Fig. 1. Stages of the Demographic Transition [12].

As into the European international context, Italy moves towards stage 5. As a matter of fact, the decrease in the birth rate, associated with a progressive aging of the population, has long been a constant, generating new challenges for governance, also in terms of spatial accessibility of the emergency health system, in response to the spatial distribution of the over 65 population [18, 19].

2.2 Inner Areas and Accessibility in Italy

The importance of providing an adequate spatial accessibility of the emergency health system represents a real challenge, especially in Italy, where the issue of the peripherality of internal areas is addressed in the scientific debate and in the political agenda [20].

The National Strategy for "Inner Areas" (SNAI) (2014) [21–23], a national development and cohesion policy, defines a polycentric structure of Italy, characterized by a system of urban centers and peri-urban areas, and by a series of medium and small municipalities, characterized by a different level of accessibility, calculated in terms of travel time necessary to reach the nearest urban center [24]. More precisely, urban center and peri urban areas correspond to those municipalities or aggregations of municipalities where the offer of primary services such as secondary schools, hospitals with a Department of Emergency and Acceptance (DEA) level I and platinum, gold or silver train stations is concentrated and accessible within 20 min ($t = 20$ min).

Instead, the municipalities falling within the so-called "internal areas" are identified based on the level of accessibility to the three citizenship rights mentioned above (mobility, education, and health): intermediate areas ($20 < t < 40$ min); peripheral areas ($40 < t < 75$ min); ultra peripheral areas ($t > 75$ min). The proposed classification reflects the degree of spatial peripherality.

The marginal territories, characterized by important geographical or demographic disadvantages, distant from the main urban centers and services, cover a total of 60% of the country's total area, 52% of the Municipalities and 22% of the population [25].

The ISTAT report (2023) on the accessibility of Italian municipalities to infrastructure nodes relating to four types of transport networks (road, railway, maritime and air) [26], states that:

- approximately 53% of the municipalities and 75% of the population are half an hour from the nearest train station.
- approximately 38.9% of municipalities and 60% of residents can access the motorway network within 15 min.
- approximately 14% of municipalities and 35.8% of the population can reach the airport within 30 min.
- only 9.4% of the population (85 Municipalities) reaches a passenger port within 15 min.

Another ISTAT report (2024) on the accessibility of Italian municipalities to the mail public services (pharmacies, emergency rooms, police, municipal offices, food shops and markets, supermarkets) [27], reveals that 50.8% of families have difficulty reaching the emergency room, an increase of 1.6 percentage points compared to 2022. The highest percentages are found in the South (59.5%, approximately seven percentage points more than the national average), followed by the Islands and the Center (52.7% and 52.4% respectively). The value exceeds the national average in some regions (11). The highest percentages are recorded in Campania (63.5%), followed by Calabria (62.5%), Liguria (58%) and Puglia (57%). The difficulty of Italian families is greatly influenced by the spatial distance to the emergency rooms. As a matter of fact, in the Metropolitan areas, the difficulty is equal to 43.8%, while in the small municipalities (under 2,000 inhabitants) it rises to 68.6%, thus increasing the perception of marginality and peripherality.

In this sense, investments in territorial resources and accessibility to counteract the marginalization and demographic decline of inner areas are at the core of the SNAI. Spatial accessibility represents a precondition for developing policy and territorial planning strategies: the level of accessibility to an infrastructure or a primary service affects the quality of life and the competitiveness and productivity of businesses.

3 Materials, Data, and Methods

3.1 Study Area

The Autonomous Region of Sardinia (ARS) is an Italian island region with 1,578,146 inhabitants (2023). It extends for 24,090 km2, representing the second largest island in the Mediterranean, after Sicily, and the first Italian region for coastal development (1,897 km). The administrative division consists of provinces - Nuoro (NU), Oristano (OR), Sassari (SS), South Sardinia (SU) -, a metropolitan city - Metropolitan City of Cagliari (MCC) - and 377 municipalities.

Like Italy, the Sardinia region is affected by the phenomenon of demographic decline. In the last 10 years (2013–2023) it lost 85,713 inhabitants. According to ISTAT forecasts, the Italian population will decrease from 59 million on 1 January 2022 to 58.1 million in 2030, and again from 54.4 million in 2050 to 45.8 million in 2080 [28].

The decrease will be even more marked in Sardinia, where in 2022 the lowest level of fertility in Italy and the minimum value of children per woman was recorded [29]. The Sardinian population has an age structure that is significantly older than the Italian average [30]. In 2021 the regional average age is 48.1 years, higher than the national average of 46.2 years.

Within this framework, one of the most complex challenges is the optimization of the provision of the health system to respond to the demand for assistance, in particular from the older segments of the population.

However, guaranteeing adequate levels of healthcare represents an arduous challenge, especially as regards spatial accessibility to the HEN, threatened by significant mobility gaps, in extra and intra-territorial continuity. As a matter of fact, the primordial condition of disadvantage in the extra territorial continuity (movements to and from Sardinia) is worsened by a weak offer of transport services and infrastructures (especially with reference to roads and railways) [31]. Travel times for movements within the island, among the highest in Italy, further aggravate the condition of insularity [32] and requires a renewed public governance capable of addressing the challenges of the demographic transition [33], guaranteeing an age-friendly region [34].

3.2 Method

Several studies analyze the relationship between the quality of healthcare and the main demographic indicators (life expectancy at birth, longevity, mortality rate, etc.) [35–37], proposing methods to measure the potential travel times needed by the population to reach health services [38, 39].

Within this framework, the authors propose a methodological approach to evaluate the spatial accessibility to the hospital emergency network (HEN). The study uses

Network Analysis (NA) techniques to analyze the spatial distribution of the population, especially the population ages 65 and above, thus detecting the level of accessibility to the HEN by public and private means of transport. Spatial network analysis is used to analyze the spatial relationships between nodes in a geographic network [40]. Processing network analysis tools in QGIS support the calculation of:

- the shortest and/or fastest path between two points of a network (shortest path /layer to point; shortest path/point to layer; shortest path/point to point).
- the areas reachable from a specific point, chosen manually or from a point layer, based on a specific distance or time (service area/from point; service area/from layer).

More precisely, starting from a specific spatial typology, in which the geographical position of the nodes (points) and connections (arcs) within the network is identified, the network analysis allows the evaluation of spatial accessibility, i.e. the degree of ease with which a node can be reached from other points of the network, considering spatial characteristics. In this sense, processing network analysis tools also support the definition of isochrones, i.e. maps that show the areas that can be reached within a given time from a starting point, considering variables such as travel speed and the road network, or the speed of public transport available. Isochrones can be calculated for pedestrians, cars, bicycles, or public transport. Isochrones can be used to evaluate the coverage of services and the level of accessibility, providing useful support to several disciplines, including urban planning and transport planning.

GIS (Geographic Information Systems) software and online mapping applications offer tools to generate isochrones [41]. The Travel Time application plugin [42], for example, adds a toolbar and processing algorithms allowing to query the TravelTime API directly from QGIS. The TravelTime API allows to obtain polygons based on travel time using different transport modes. TravelTime public transport model considers every possible route based on public transport timetables and data gathered from public transport agencies. Data comes from a continuous collection of public transport timetable data (GTFS data or timetables in other formats), incorporated into the TravelTime public transport model, and updated at least every two weeks. Several combinations of public transport methods are included, covering bus, coach, train (overground train, underground train), and tram. Walking is also included, to allow for moving between stops/stations etc.

3.3 Data

Data collected to assess the spatial accessibility of the Sardinian population, in particular the elderly (> 65 years), to the nodes of the HEN, by both private and public transport, are as follows (Table 1):

- census population [43], which provides information on the main characteristics of the resident population (sex, age, education, occupation, marital status, families), in reference to each census section.
- administrative boundaries (municipalities, provinces, metropolitan city) [44].
- nodes of the HEN [45], i.e. the services considered fundamental to evaluate the level of marginality and peripherality of the municipalities, in line with the SNAI

objectives. The 22 nodes located throughout the regional territory (data updated as of 30 December 2021) [46] are as follow: n. 11 emergency rooms (ER); n. 8 DEA Level I, located in the four provinces and in the Metropolitan City of Cagliari; n. 3 DEA Level 2, located in the Province of Sassari and in the Metropolitan City of Cagliari.
– Road network [47], fundamental for defining the isochrones and, therefore, calculating the population that can reach the nearest node of the HEN in a given time (20 min), through private or public transport.

Table 1. Dataset to support NA in the ARS.

Data	Source	File extension	Date
Census population	ISTAT [43]	xlsx, shp	2021
Administrative boundaries	ISTAT [44]	shp	2023
Nodes of the HEN	Ministry of Health [46]	xlsx, shp	2021
Road network	ARS_Geotopographic Database [47]	shp	2022

4 Results

In this study, the NA techniques of the QGIS software are used to define 20-min isochrones from the nodes of the Sardinian HEN, in order to evaluate the accessibility of the population, especially the over 65 population, through public and private transport modes. In particular, the Travel time application is used to evaluate accessibility by Local Public Transport (LPT). The results of the NA techniques used to evaluate the accessibility to the HEN nodes through private means of transport are presented below, considering a travel speed of 50 km/h (Fig. 2). Figure 2 also shows the TrivelTime 20-min isochrones by LPT, with reference to the 3 DEA Level I located in the cities of Olbia, Nuoro and Cagliari.

NA techniques reveal that 66.14% of the Sardinian population lives in urban centers equipped with a HEN node and in peri-urban areas (which reach the urban center in 20 min), while the rest live in inner areas. Moreover, 35.05% of the elderly Sardinian population live in inner areas.

In the MCC, the resident population is equal to 422,499 inhabitants, of which 102,936 are elderly (24.36%). The MCC records the highest levels of accessibility to the HEN nodes, exceeding the regional average by several percentage points: 88.20% of the population lives in urban centers and surrounding areas. The most populous province, that of Sassari (SS), with 476,516 inhabitants, of which 24.55% are over 65 years old, records levels of accessibility to the HEN nodes closer to the regional average: 67.22% of the population lives in urban centers, 32.79& in internal areas. The lowest levels of accessibility are recorded in the following provinces: Nuoro (NU), Oristano (OR) and South Sardinia (SU). More precisely, in the province of Nuoro, almost 64% of the total population and over 63% of the elderly population live in inland areas. The same provinces also record the lowest life expectancy values compared to the regional and national average.

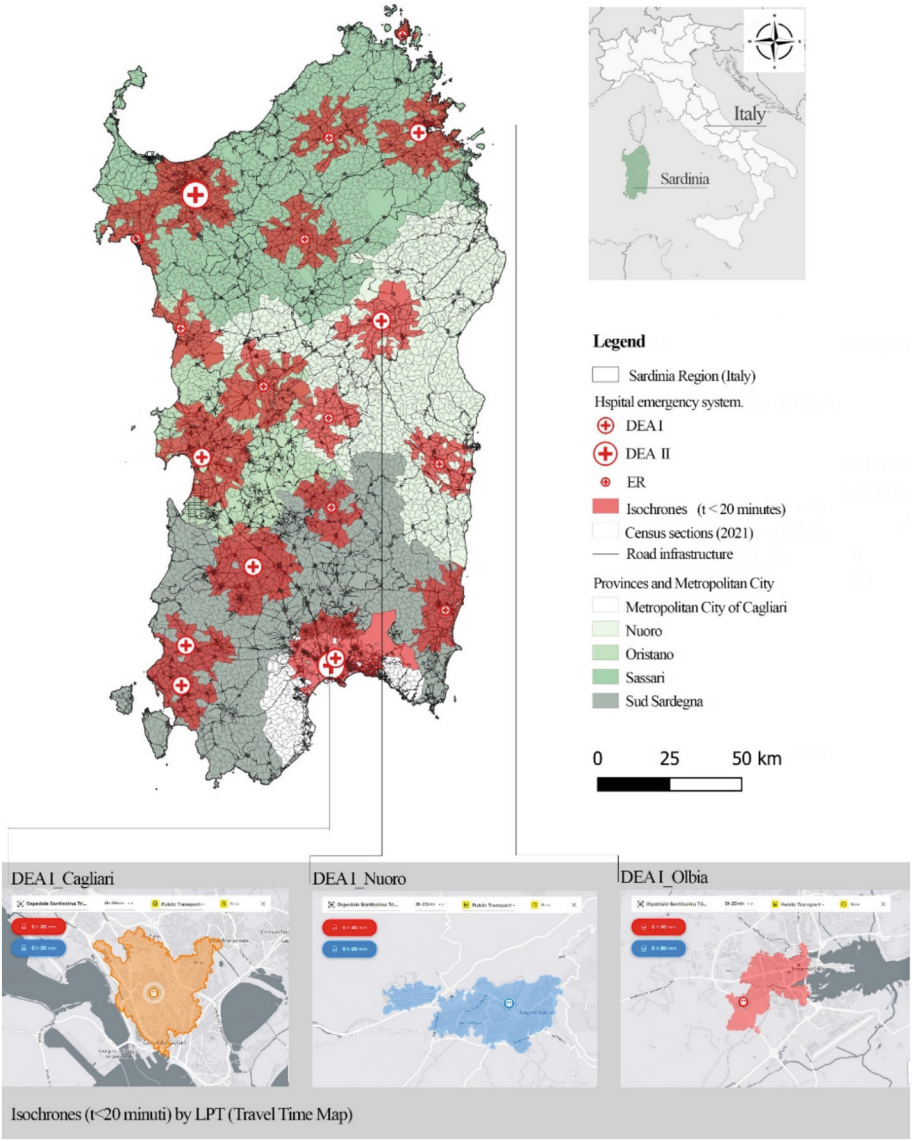


Fig. 2. At the top, the isochrones (20 min from each node of the HEN) by private transport. Below, the isochrones (20 min from the DEA I of Cagliari, Nuoro and Olbia) by LPT (Source: Travel Time Map). Author: Mara Ladu

According to the Provincial BES indicators [48], in 2022, life expectancy at birth in Sardinia (82.5 years) is slightly higher than the national value. The province of Cagliari is the one with the highest value at a regional level (83.8 years), higher than the national

average Fig. (82.4 years), while that of Nuoro records the lowest value (81.7 years), i.e. almost one year less than Sardinia and Italy. Low values compared to the regional and national average are also recorded in the provinces of Oristano and South Sardinia (Table 2). This explains the close relationship between health policies, well-being, and demographic transition.

Table 2. Life expectancy at birth. Data on provincial, regional, and national level.

Indicator	Territorial scale	Cagliari	Nuoro	Oristano	Sassari	South Sardinia
Life expectancy at birth	Province	**83,8**	**81,7**	**82,0**	**82,5**	**82,2**
	Region (Sardinia)	82,5	82,5	82,5	82,5	82,5
	Country (Italy)	82,4	82,4	82,4	82,4	82,4

5 Conclusions

The authors proposed a methodological approach that applies the Network Analysis (NA) technique to analyze the spatial distribution of the population, especially of the population ages 65 and above, and evaluate the accessibility to the node of the Health Emergency Network (HEN) in the Autonomous Region of Sardinia (ARS).

The results reveal that approximately 60% of the Sardinian population is concentrated in urban centers equipped with a node of the HEN and in peri-urban areas, as defined by the SNAI. The remaining population, of which 35% is over 65, lives in the inner areas: intermediate areas; peripheral areas; ultra-peripheral areas.

The geographical spatialization of the population, classified by age target, deserves particular attention by virtue of the demographic transition. As a matter of fact, the recent forecasts developed by ISTAT on demographic dynamics (2023–2031) [49] reveal that the population ages 65 and above will be concentrated mainly in the municipalities that are part of the I and II belt of metropolitan cities.

The method based on network analysis can be applied in other regional contexts, also to develop comparative studies to support urban and transport planning, as well as policies in those areas where low levels of accessibility to the HEN have been recorded, considering the opportunities provided by the MaaS solutions. In this sense, the study is part of the research activity developed to create the multilevel geodatabase of the e.INS project, which intends to propose forms of sustainable mobility in the extra- and intra-territorial continuity) [50] in a space of proximity to guarantee the right to health.

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