Assessing the Potential of Demand Responsive Transit for Non-Emergency Healthcare Travel: An Accessibility-Based Approach

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Abstract. Demand Responsive Transit (DRT) is an important transport alternative that aims to promote greater sustainability in accordance with the goals of Agenda 2030. The possibility of implementing DRT must be considered in the presence of demand niches that are not covered by local public transport or other available transport modes. Among these demand niches, the demand for non-emergency healthcare travel is of particular interest due to its social implications.

This article proposes an aggregate methodology for the aggregate analysis of accessibility to hospital systems, to understand potentiality for implementation of DRT services. By combining the analysis of the accessibility of the hospital system and the study of the existing local public transport system, it is possible to identify suitable areas for further investigation of the applicability of a DRT system. Three attributes are analysed, based on available open-access data: distance to the nearest hospital, resident population and presence of a local public transport service. A pilot study is shown in which the proposed analysis is conducted considering the municipalities classified as "inland areas" of the Sicilian Region in Italy. The results show a poor condition of the mobility service system, highlighting how further analyses can be developed in the investigated area. The proposed model makes it possible to identify the areas in which DRT systems can help to support segments of demand for non-emergency healthcare travel.

The research is a prerequisite for a demand survey in areas characterised as critical, to assess the applicability of DRT services for healthcare trips. The research is of interest to public administrations, companies operating in the urban and suburban transport sector and researchers.

Keywords: Demand Responsive Transit · Healthcare accessibility · Non-emergency medical transport · Local public transport · Inland areas

1 Introduction

Health has assumed a significant role in humanity's sustainability goals. The United Nations 2030 Agenda for Sustainable Development outlines a global framework within which mobility policies and access to health services have a strategic and urgent place [1]. The 17 Sustainable Development Goals (SDGs) represent the global challenges to

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O. Gervasi et al. (Eds.): ICCSA 2026 Workshops, LNCS 16761, pp. 284–298, 2027.
https://doi.org/10.1007/978-3-032-30527-5_19

be addressed, further broken down into targets, specific results to be achieved; indicators are defined to measure progress in achieving the results [2, 3]. Among the 17 SDGs, Goal 3, "*Ensure healthy lives and promote well-being for all at all ages*" stands out. It establishes the principle of universal access to healthcare, defining equity in the provision of care as a prerequisite for community well-being. Target 3.8 states "*Achieve universal health coverage, including financial risk protection, access to quality essential healthcare services, and access to safe, effective, quality, and affordable essential medicines and vaccines for all*" explicitly defining health coverage for all. In this context, ensuring universal health coverage is not limited to providing adequate medical facilities and personnel; it also implies the concrete possibility for every individual to reach places of care.

In this sense, it is essential to emphasize the role of Goal 11 "*Make cities and human settlements inclusive, safe, resilient, and sustainable*". While target 11.1 identifies the need to provide access to basic services to all citizens, target 11.2 calls on Countries to ensure safe, affordable, accessible, and sustainable transport systems for all by 2030, with priority attention to the most vulnerable: older people, people with disabilities, women, and children. SDG 11 therefore highlights how mobility is not merely an infrastructural issue, but a social determinant of health.

Alongside these two objectives, with specific relevance to this paper, is Goal 9 "*Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation*", which promotes the development of resilient and inclusive infrastructure and supports the adoption of innovative technological solutions at the service of the community.

Accessibility to hospital facilities is therefore an element at the intersection of different areas of sustainable development; specifically, elements related to health, community well-being, and the sustainability of cities converge. In this context, the study of healthcare mobility becomes relevant. A portion of healthcare-related travel is not related to emergency situations, but to scheduled visits or diagnostic tests. These non-emergency healthcare trips have specific characteristics: generally, they can be planned and often involve categories of users—the elderly, people with mobility disabilities, chronic patients—who do not have their own transportation or are unable to drive independently [4–7].

Due to its characteristics, scheduled public transport services may not be suitable to effectively respond to these needs, both due to the rigidity of the routes and to a structural difficulty in responding to door-to-door mobility [8]. In this context, DRT service emerges as a suitable response tool to various emerging problems. It is an on-demand, bookable service with intermediate rigidity characteristics between those of a classic, fully rigid PT service and a fully flexible taxi, for which it is defined as a semi-rigid service [9, 10]. Most of these services, in fact, have lines with fixed routes, but with the possibility of making detours based on booked stops. Services based on low-capacity vehicles are often more efficient in contexts characterized by limited or variable demand, as they allow for better adaptation of the offer to different time slots, avoiding the mismatch between vehicle capacity and number of users that frequently characterizes conventional public transport services [11].

This paper proposes a general framework for studying hospital accessibility, with the aim of identifying areas not served by public transportation, including hospital facilities and the affected population. In these areas, it is possible to consider implementing on-demand services. The proposed framework relies entirely on the use of open databases to ensure the study's replicability and scalability.

The remainder of the paper is organized as follows. Section 2 describes the state of the art, recalling the most significant contributions to the study of healthcare facility accessibility via public transportation. Section 3 outlines the main methodological components discussed in the paper. Section 4 presents the case study and the results of the application. Finally, Sects. 5 and 6, respectively, discuss the results and present the conclusions, limitations, and future developments of the research.

2 State of the Art

Demand Responsive Transit (DRT) can be framed as a flexible, user-oriented component of public transport systems, designed to adapt routes and schedules to actual demand rather than fixed timetables. It is typically deployed to complement conventional services in low-density or underserved areas, where fixed-route operations are inefficient or economically unsustainable [12]. Its effectiveness depends on the balance between service flexibility, operational costs, and user convenience, considering developing a network of DRT lines to serve an area already served by existing public transport, substitution of conventional bus lines or introduction of a service in an area not served by public transport due to low demand [13]. DRT are identified as a mode of transport who can improve hospital accessibility [14] [15]. identify hospital access as one of the market niches potentially interesting for the implementation DRT services. The authors define a separation between potential DRT users for hospital services, identifying staff, patients, and visitors as possible DRT users, staff trips more frequent and generally shorter, while patient and visitor trips longer and with highly variable frequencies. Furthermore, they underline how different services are operated by both car volunteers and equipped minibuses; services tend to be primarily door-to-door.

[16] highlight that published literature underlines how high costs is a major failure factor for DRT systems; on the other hand, specialist social-service-based DRT systems have been considered to warrant justifiable subsidies. From this perspective, therefore, it is necessary to emphasize the social component of a service to improve hospital accessibility. Temporal accessibility also plays a role in designing a DRT service for hospitals; a misalignment between a service's operating hours and the demand for hospital services could lead to a reduction in demand for these sectors [17].

The study of quantitative methodologies for analysing healthcare accessibility is a recently emerging topic in literature. Several studies have applied quantitative methodologies to assess how effectively public transportation networks enable the population to reach hospitals and healthcare services.

[18] analyse accessibility and equity in access to hospitals in six major cities in Ohio (USA), using indicators based on travel time by public transportation. The results highlight significant spatial disparities between central and peripheral areas, with lower accessibility in suburban areas. In a similar way, [19] conduct a comparative study of eight

Canadian metropolitan areas, showing how differences in the structure of transportation networks and the distribution of hospitals strongly influence accessibility levels.

Other works focus on specific European urban contexts [20]. analyse the case of Rome through a complex network analysis approach, highlighting how the structure of the public transport network influences connectivity between neighborhoods and healthcare facilities. Similarly, [21] propose a spatial analysis methodology applied to the city of Milan, using accessibility mapping techniques to identify urban areas with a potential lack of access to health services via public transport.

In North American context, [22] model multimodal access to primary care in an urban context, highlighting the importance of integrating different transport modes (public transport, active mobility and private vehicles) to improve overall accessibility [23]. proposes a comparative analysis of hospital accessibility in the city of Córdoba (Argentina) between 2019 and 2023, highlighting how changes to the public transport network can produce significant variations in access times to health services.

The studies show some methodological similarities, including the use of travel time-based indicators and the use of GIS tools for spatially assessing accessibility. However, significant differences also emerge in case studies, scales of analysis, and methodological approaches adopted, ranging from complex network models to multi-city comparative analyses. This heterogeneity reflects the need to adapt analysis tools to the specific territorial characteristics of transportation networks and the distribution of healthcare infrastructure.

The contributions focus primarily on large urban areas, with widespread public transport systems and a supply system with different modal alternatives and access to transportation. This paper investigates an urban-rural area, with the presence of small and medium-sized towns and large areas of low population density, with the aim of identifying, using open-source databases, areas where the use of DRT for access to healthcare facilities could be considered as an alternative.

3 Methodology

3.1 Modelling

The aim is to define an indicator that allows us to assess public transportation coverage for access to healthcare facilities in the study area. To formalize the problem, four subsets of information are defined based on the main components of the transportation system. For the modelling, reference is made to a transportation system modelling (TSM) approach [24–26].

The first subset is the set Z of N zones in the study area, defined as $Z = (z_1, z_2, \ldots, z_n, \ldots, z_N)$. Each zone in set Z can be characterised by different quantitative attributes, such as the population P_n and the surface area A_n. The population distributed across the territory allows us to model the demand side of the analyzed system.

The second subset is $H = (h_1, h_2, \ldots, h_w, \ldots., h_W)$, the set of healthcare facilities. The facilities are the points on the territory that indicate the potential destinations of healthcare trips and serve to represent the activity system. For simplicity, in the following we will refer to a case of a single hospital facility h in the study area. The third subset

$L = (l_1, l_2, \ldots, l_m, \ldots, l_M)$ represents the set of public transport lines; the fourth subset is $S = (s_1, s_2, \ldots, s_k, \ldots, s_K)$ the set of public transport stops. These two components represent the supply system.

Sequentially, it is necessary to define some conditions that allow to verify whether it is possible to reach h from the generic zone z_n via public transport.

The first is the condition of belonging of the generic stop s_k to the generic line l_m. The analytical definition of the first criterion specifically concerns the modeling of the timetable. It is defined as

$$A(s_k, l_m) = \begin{cases} 1, & \textit{if } s_k \textit{ is served from } l_m \\ 0, & \textit{otherwise} \end{cases} \tag{1}$$

The second condition concerns stop. It is necessary to define whether the generic stop s_k can is a stop serving the hospital. Having identified a generic distance *DIST*, the maximum threshold for walking between a public transport stop and a destination hospital and having evaluated the distance between s_k and h as $dist(s_k, h)$ it is possible to define $B(s_k, h)$ as

$$B(s_k, h) = \begin{cases} 1, & \textit{if } dist(s_k, h) < DIST \\ 0, & \textit{otherwise} \end{cases} \tag{2}$$

Starting from this condition, it is possible to define the set of lines that serve the hospitals L_h.

$$L_h = (l_m \in L | \exists s_k : A(s_k, l_m) = 1 \wedge B(s_k, h) = 1) \tag{3}$$

It is therefore possible to define the set S^* as the subset of S of stops belonging to at least one line of the set L_h.

$$S^* = \left\{ s_g \in S | \exists l_m : A\left(s_g, l_m\right) = 1, l_m \in L_h \right\} \tag{4}$$

The s_g stops are the set of stops that, belonging to a l_h line that makes a stop near the hospital, are eligible for accessibility to the facilities. Assuming a threshold Δ of maximum pedestrian distance for access to the public transport stops, we can evaluate the isodistance i_{Δ, s_g}, sg, the set of points distant Δ from the generic s_g, and the isodistance i_Δ as the overall isodistance.

Therefore, for each z_n, it is possible to describe an area $A_{n,\,\Delta}$, as the portion of the area A_n of the zone z_n contained within the isochrone i_Δ. Assuming the population is uniformly distributed across the surface of each zone z_n, it is possible to evaluate both the percentage of population and the total population living at a distance of Δ, or minor, in each zone z_n.

$$\%POP = A_{n,\Delta}/A_n = P_{n,\Delta}/P_n \tag{5}$$

$$P_{n,\Delta} = \%POP * P_n \tag{6}$$

3.2 Dataset

The study presented can be divided into two steps: data acquisition and data analysis. The first step concerns obtaining the data required for analysis. As previously defined, the data essentially concerns three different aspects of the transportation system:

- The demand system, expressed by the population living in the zones into which the study area is divided. The most common discretization, and generally available in open access format, is that of census zones, although the update time varies depending on national specificities. The extension of census zones allows working with the smallest aggregation available in a given country and having the most detailed information possible on population and age variables. An example is the Italian statistical agency Istat, which provides census parcels and sociodemographic variables in GIS format.
- The supply system, expressed by the lines and timetables of the operator managing public transport in the study area. The lines and timetables are always public. Open platforms such OpenStreetMap provide service routes and stop distribution in vector format.
- The activity system, expressed by the distribution of healthcare activities across the territory. The activities considered are easily reconstructed, even with the support of open platforms like OpenStreetMap, which specifically identify healthcare activity categories such as hospitals and clinics.

The general scheme is shown in Fig. 1.

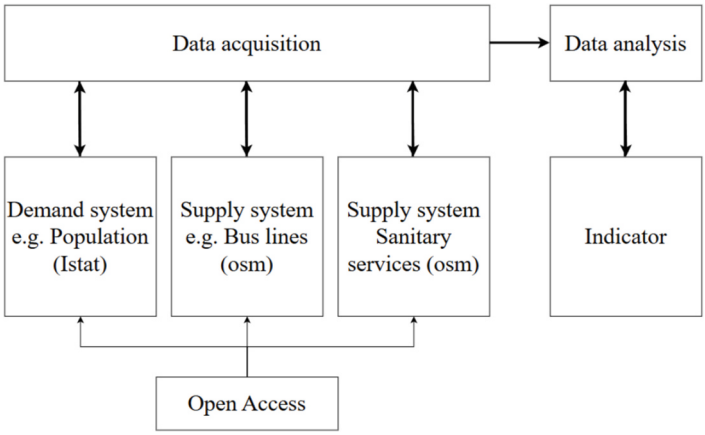

Fig. 1. General scheme of methodology.

4 Case Study

4.1 Case Study Description

The investigated area in this paper is the municipality of Enna, in Sicily, Southern Italy. It is a municipality of approximately 25,000 inhabitants located in the central part of the island (Fig. 2) [27].

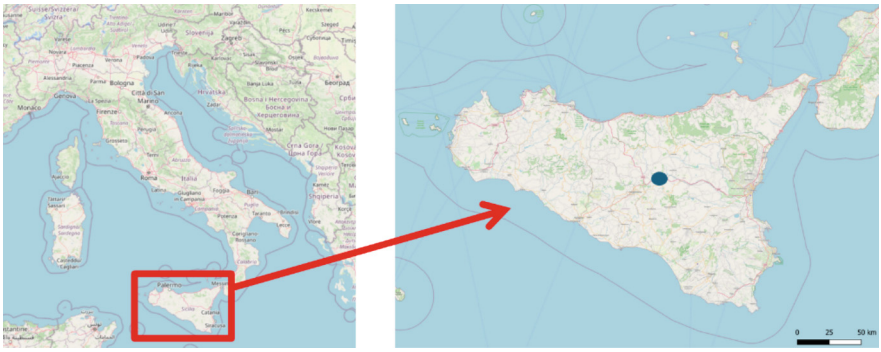

Fig. 2. Location of the study area in Italy. Source: [28].

There are three main areas where most of the population resides in the municipality of Enna: the main historic centre, the new part of the city, and a hamlet. The main town lies on a plateau approximately 900 m above sea level. The new part of the city, called "Enna Bassa," is located south of the mountain that hosts the historic centre; the new part hosts some more recently introduced services, such as the university and the hospital. To avoid confusion over names, and to reflect the different geographical location, the historic part of the city is often referred to as "Enna Alta". This area of the municipality is particularly affected by student mobility, due to the presence of the University. The municipality also includes a hamlet, Pergusa. It is located 10 km south of the main centre and has a tourism and hospitality-based economy due to the presence of a nature reserve. The remaining part of the municipality is predominantly agricultural, with large areas of extremely low population density. Figure 3 shows the study area, with the three main areas highlighted.

4.2 Results

To identify the areas, we refer to the division into census parcels established by Istat, the Italian national statistical agency. By referring to census parcels, it is possible to represent the population distribution in the most disaggregated manner publicly available. The georeferenced data on administrative borders and population are open access [29]. The population distribution on a municipal scale is shown in Fig. 4.

Figure 4 shows the highly uneven distribution of the population across the territory, with large agricultural areas and low population densities. Figure 5 focuses on the population distribution in the Enna Alta and Enna Bassa areas.

Further focus is placed on the hamlet of Pergusa. The population distribution in this area is shown in Fig. 6.

The city hospital is located in the south-eastern part of the city (Enna Bassa).

The local public transport service in Enna is managed by SAIS autolinee, through 8 lines that cover the territory of Enna Alta, Enna Bassa and Pergusa [30]. Lo schema generale delle linee è riportato in Table 1.

The eight lines cover the most densely populated areas. Line 1 connects the western and eastern sides of Enna Alta, where most of the resident population is concentrated.

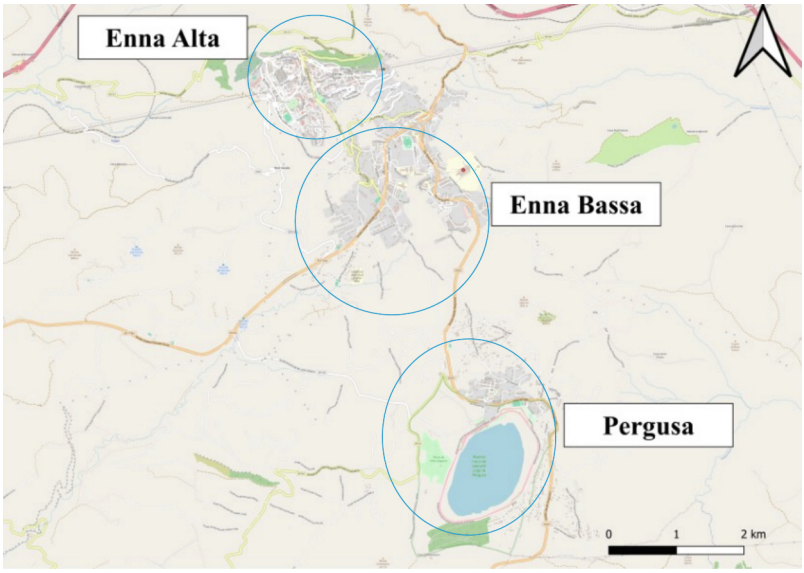

Fig. 3. Location of the three main inhabited areas. Source: [28]

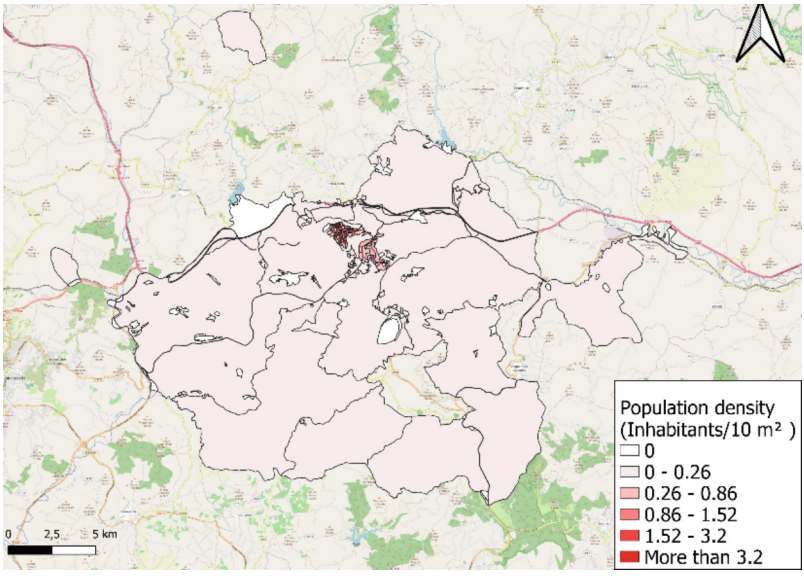

Fig. 4. Population distribution in the municipality of Enna. Source: [29]

Lines 2 and 3 connect the eastern and western sections of the old city, respectively, with the new area. Line 4 connects a large parking lot at the entrance to the old city to the city centre and serves to relieve congestion in the main residential area. Lines 5 and 6 connect the areas of Enna Alta and Enna Bassa with the southern hamlet of Pergusa.

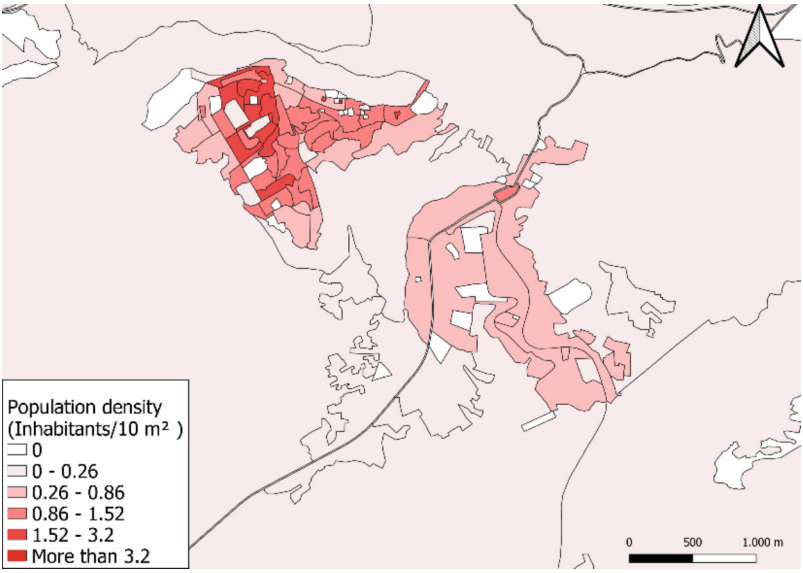

Fig. 5. Population distribution in the areas of Enna Alta and Enna Bassa. Source: [29]



Fig. 6. Population distribution in the area of Pergusa. Source: [29]

Lines 7 and 8 connect the historic centre with some school and university areas of Enna Bassa.

Table 1. Main characteristics of the lines

Line	Name
1	Spirito Santo – Valverde
2	Valverde – Ospedale
3	Spirito Santo – Università
4	Pisciotto – Piazza Garibaldi
5	T.bus Enna Alta – Pergusa
6	T.bus Enna Alta – Pergusa via Toscana
7	Piazza Europa – Enna Bassa
8	T. bus Enna Alta – Scuola Media Savarese

Of the 8 lines, 4 have a stop near the hospital: lines 2, 3, 5, 6. As an example, Fig. 7 shows the route of line 2 with respect to the towns of Enna Alta and Enna Bassa and the location of the hospital.

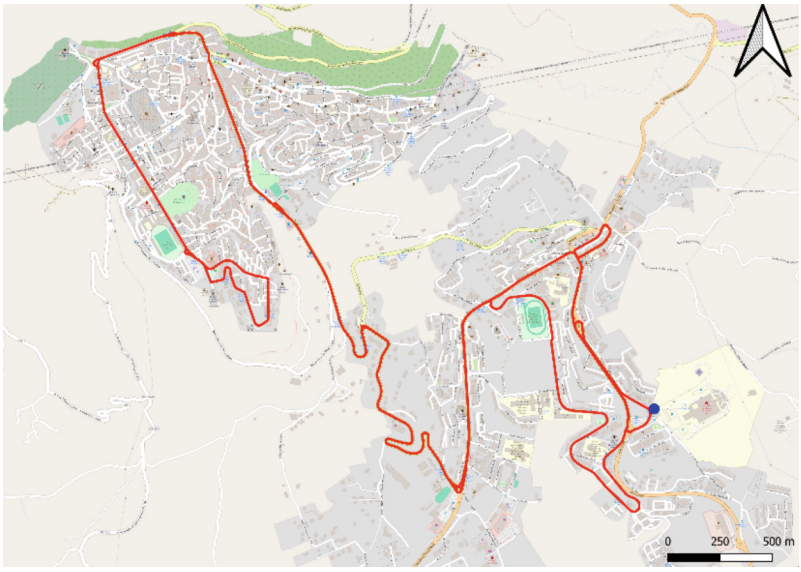

Fig. 7. Representation of the path of line 2 (red) and the positioning of the hospital (blue). Source: [28]

To study accessibility, an isodistance curve of $\Delta = 200$ m is considered. An isodistance of 200 m represents a short pedestrian distance, which can be covered in approximately 2–3 min, making it accessible to most users. This threshold reduces the effort and time required to reach a public transport stop. It also favors the use of public transport over private cars. In compact urban contexts, 200 m ensures good coverage of the area

with easily accessible stops. An isodistance of 200 m allows us to hypothesize coverage within the five-minute pedestrian period even for the older sections of the population, considering an average speed of 0.8 m/s [31]. Figure 8 shows the overall isochrone for the areas of Enna Alta, Bassa and Pergusa.



Fig. 8. 200 m Isodistance for the areas of Enna Alta and Enna Bassa (left) and Pergusa (right) [28]

The representation of the *%POP* for the census zones z_n identified in the study is shown in Fig. 9.

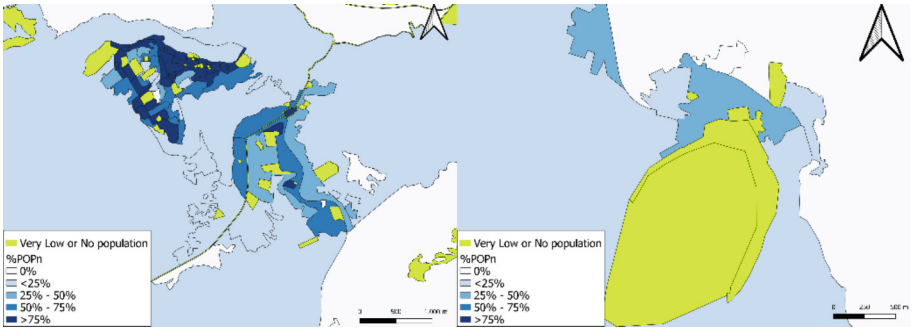

Fig. 9. POP% for Enna and Enna Bassa (left) and Pergusa (right). Source: [28]

Figure 9 highlights clear spatial patterns in accessibility, with higher coverage concentrated in the central and more densely populated areas, particularly in Enna Alta, while peripheral and low-density zones exhibit significantly lower values. The presence of public transport lines strongly influences the spatial distribution of accessibility, generating clusters of well-served areas around main corridors and leaving more fragmented coverage in recently developed or rural zones.

5 Discussion and Conclusion

The results show the distribution of the population covered by the 200 m walking distance from the transport supply system for accessing the hospital. The study area exhibits significant territorial differences, mainly related to the rural nature of the territory under consideration. The results in terms of POP% highlight how the lines offer good population coverage in the Enna Alta area, which is served by four lines connecting it to the hospital. Aside from a few zones in the central part of the city, Enna Alta have almost uniform coverage above 50%, exceeding 75% in some zones directly hosting one or more stops. In these zones, population coverage for hospital access can be improved not by the introduction of new services but by improving connections in uncovered areas. The potential adoption of potential on-demand services in these areas necessarily requires an assessment of time slot coverage. The adoption of new services must consider primarily temporal integration with existing public transport services that offer good territorial coverage.

The Enna Bassa area offers different results. The area is less densely populated, but there is a difference in coverage between the northern and eastern parts of the city, compared to the western part, particularly the southwest, where coverage remains below 25%. These more recently built residential areas represent the city's expansion area and could see future improvements in connectivity, especially due to the presence of university facilities. The introduction of DRT services, in this case too, must consider integration with pre-existing services.

Pergusa represents a different case compared to the two areas previously described. The main area achieves good coverage (40%) thanks to the two lines that pass along the main road. The resident population is low, while the area, due to the presence of numerous tourism-related activities like natural attractions and the Pergusa racetrack, sees significant seasonal flows. The distance from the main city, approximately 10 km, is relevant, especially for vulnerable population groups. These factors necessitate further demand analysis to evaluate the implementation of on-demand services.

An interesting topic remains the study of accessibility for all areas outside the three urban areas described. These areas, primarily agricultural, are very extensive, and a more disaggregated distribution of residential areas is not available; although sparsely populated, many areas of the municipality of Enna are home to a significant resident population, exceeding 500 people in some areas. The presence of residential buildings in such sparsely populated areas makes these areas potential locations for the presence of DRTs connecting to healthcare facilities in the central part of the city.

This paper presents a spatial approach for analyzing hospital accessibility via local public transportation. The methodology is based on entirely open-source data, is replicable, and scalable across a wide range of contexts. The results provide clear guidance for the implementation of DRT systems as a complementary layer to existing public transport. In areas with relatively high coverage, such as Enna Alta, DRT could be designed to improve first/last-mile connectivity and address residual gaps. In low-coverage areas such as the southwestern part of Enna Bassa and dispersed rural zones, DRT services could play a more structural role by ensuring direct access to healthcare facilities, especially for mobility-constrained users. In these areas, the spatial configuration of demand

suggests the adoption of flexible routing schemes, such as door-to-door services with variable itineraries, capable of adapting to scattered settlement patterns.

This study presents some limitations that should be acknowledged. Population is treated as uniformly distributed within census units derived from Istat data. Also, the adoption of a fixed walking threshold to access public transport does not account for heterogeneity in individual capabilities, trip purposes, or built environment characteristics. In addition, the analysis is based on aggregate indicators and does not explicitly consider service frequency, reliability, or temporal variations in accessibility. Future research could address these limitations by integrating more disaggregated population data, variable walking thresholds, and dynamic transport supply attributes, as well as validating results through user-based demand surveys.

The proposed study is a preliminary assessment, requiring further exploration with demand analyses aimed at identifying users most interested in a DRT service. The assessment conducted considered the resident population as the demand variable; further specifications can consider the percentage of the population by age group or according to criteria based on other socio-demographic variables. The paper highlights how zones with low population density, high land area, and a significant population are those in which more in-depth demand analyses are needed. Extensions of the model could include temporal variations and the frequency of hospital services, allowing for a more dynamic representation of accessibility conditions. Incorporating time-dependent factors, such as opening hours of healthcare facilities or public transport service frequency, would enable an assessment of actual service temporal availability. This approach could support the design of a services spatially and temporally optimized.

The applicability of the proposed methodology extends beyond the case study and can be explored through benchmarking with other territorial contexts in Italy and abroad. The framework can support comparative studies by analysing how gaps in healthcare accessibility vary based on different spatial structures and the extent to which existing public transport networks can be effectively integrated with Demand Responsive Transport services. This perspective is especially relevant in the Italian context, where many territories share structural characteristics similar to the case study, analyzed in this work, including small and dispersed settlements, low-density populations, and predominantly rural or inland configurations. Such conditions are widespread across inland areas, suggesting a high potential for replication of the proposed approach. By applying the same set of indicators to different regions, it is possible to identify recurring patterns and context-specific conditions that influence DRT feasibility, thereby enhancing the transferability of the results and supporting decision-makers in tailoring DRT strategies to diverse geographic and socio-demographic contexts.

The paper is of scientific interest for different categories, in particular for public authorities and territorial and transport planners, as it provides a replicable and scalable methodology for the analysis of accessibility to health facilities through public transport, entirely starting from open data.

Acknowledgments. Research is supported by the MUR (Italian Ministry of University and Research) through SMART3R-FLITS: SMART Transport for Travellers and Freight Logistics Integration Toward Sustainability (Project protocol: 2022J38SR9_03, CUP Code:

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Credit Author Statement This paper is the result of the joint work of the authors. In particular, the "Abstract", "Introduction" and "Discussion and conclusion" were jointly written by the authors. AR and TC wrote "State of the art". AR wrote "Methodology" and "Results".

Disclosure of Interests. N.t.d.

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