GIS-Based Transport Accessibility Analysis to Community Facilities in Mid-Sized Cities

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GIS-Based Transport Accessibility Analysis to Community Facilities in Mid-Sized Cities

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Abstract. Transport accessibility is an important issue for the sustainable development of cities. This work presents a GIS-based accessibility analysis approach that can be applied to assess accessibility to community facilities in medium-sized cities using publicly available data. For that purpose, a case study was developed using the road network and public transport data from Covilhã municipality, in Portugal. Data collected on websites were treated and organized to build the network dataset and perform network analyses with the aid of the ArcGis® Network Analyst extension (creation of service areas and Origin-Destiny (OD) cost matrices). Four accessibility evaluation analyses were performed for two transport modes: accessibility to the municipality main community facilities by private and urban public transport (isochronous and OD matrices), by inter-urban public transport (time); and accessibility by private transport between civil parishes (isochronous and OD matrices). The population and the territory covered by different travel times were also determined. The case study results showed that the accessibility in Covilhã is quite reasonable, either using private transport inside the municipality (maximum 30 minutes for covering nearly 95% of the resident population and 83% of the territory), or urban public transport inside the urban perimeter (maximum 50 minutes). However, the periphery civil parishes of the municipality have lower levels of accessibility for inter-urban public transport (reaching 115 minutes). The utility of the approach was validated through the results obtained in the case study, where it was possible to observe patterns of accessibility across the municipality for the considered modes, making it possible to improve the overall accessibility through the identification of priority areas of intervention.

1. Introduction

The European Union foresee sustainable mobility as a common and essential objective for territorial policies and strategies. In this sense, innovative solutions have been stimulated through European policies in order to provide citizens, living in cities, towns or villages, with conditions and choices of accessibility and mobility that deliver safe and comfortable journeys, with acceptable times and affordable costs [1].

With the increasing development of regions, the concept of accessibility and its evaluation has gained significant importance in the management of the territory. The study of transport accessibility makes it possible to understand the ability to reach certain destinations, depending on transport modes, urban living experience, location in the territory, and goods, services or activities to which access is sought. It is a precondition for people to participate in society as well as for the economic development of cities,

regions and countries [1,2]. Improving accessibility can increase social and economic opportunities and promote environmental goals, therefore it is considered an important component of sustainable development [3,4].

To assess accessibility, Geographic Information Systems (GIS), which is a valuable tool for visualizing spatial data and building decisions support systems [5], it has been used to determine service areas (for travel times and distances), OD cost matrices (for straight-line or network distances, travel time or costs) and more elaborate accessibility analysis [4, 6–8].

This work presents a GIS-based accessibility analysis approach that can be applied to assess accessibility to community facilities in medium-sized cities using publicly available data (road network, community facilities location and official statistical data on the population). The municipality of Covilhã (Portugal) was chosen as a case study, since there are no extensive road accessibility analyses covering the entire territory of the municipality that can be used to effectively assist municipal management. Taking into account this fact, an attempt to explore the accessibility level of community facilities located in the urban area of Covilhã (health and other services, educational establishments and bus/train central stations) by individual and public transport, has been made in this study.

2. GIS, transport accessibility and municipal management

The territorial planning instruments adopted in Portuguese municipalities (Municipal Territory, Municipal Master, Urbanization, Detailed and Mobility and Transport Plans) enable policy-makers to establish intervention strategies aimed at improving the conditions of accessibility of the population, anticipating and minimizing the problems that may exist in the territory.

It is possible to consider, for different types of municipal plans, specific measures of road accessibility. In this way, shorter-path network analysis (distance and/or time) are usually performed at the level of the Municipal Territory Plan for specific points of interest based on the assignment of speeds by road type (defined according to the function and capacity of the road segments) and transport mode, resulting in O-D matrices and service areas. At the level of the Municipal Master Plan, distances between important points of the urban structure (transport stops and hubs, community facilities, centroid of residential areas, services, etc.) and travel times by transport mode are calculated. In Detailed Plans, the evaluation of pedestrian accessibility to services, facilities or public transport stops, is performed.

These analyses are usually time-consuming and may result into unreliable outcomes if there is no reliable system for compiling, organizing and analysing all the information involved. As GIS allows the organization and manipulation of large amounts of georeferenced spatial and alphanumeric information, it has been used to support municipal management, being widely recommended as a tool to support governance. Given these particularities, GIS has been adopted as a tool to carry out accessibility analysis in an organized, fast and reliable way, supporting the decision-making process.

Among the proprietary, free and open source GIS software alternatives available for measuring accessibility of networks, the Network Analyst extension of ArcGis® was chosen to evaluate the road network under study. This extension of ArcGis® uses a configurable network data model that enables the user to plan routes and calculate the shortest travel time, find the nearest facility, create isoline maps (of distance, time, cost, etc.), create OD matrices and solve problems and needs of network analysis.

3. Case study: Transport Accessibility Analysis to Community Facilities in Covilhã Mid-Size Citiy

3.1. The Municipality of Covilhã

The municipality of Covilhã is located on the Central region of Portugal (NUTS II), district of Castelo Branco, on the eastern slope of Serra da Estrela. It has 21 civil parishes (5 located within the urban perimeter) comprising a total area of approximately 550 km². It has a population of approximately 51800 resident inhabitants (Census 2011), 59.5% of which belong to the age group 20-64 years and 23.7% are over 65 years old. The elderly population has grown significantly in recent years [9].

The municipality has an extensive road network with approximately 1851 km and is crossed by the Beira Interior Motorway (A23), one of the main routes connecting the country to Europe. Among the

main road axes are the Nacional Road 18 (EN18), which connects the municipalities of Castelo Branco, Covilhã and Guarda, and the Tortosendo-Covilhã-Teixoso (TCT) local road axis. The municipality has a public transport network that includes services of taxi, train, urban (Covibus) and interurban buses.

Covilhã presents a comprehensive set of community facilities, health services, sports, leisure, education, culture and commerce, among others, most of which are located in the urban area of Covilhã. The remaining parishes present services of small dimension as minor health services, primary schools and parish councils.

3.2. Methodology

The present study aims to evaluate the accessibility between the civil parishes of Covilhã and 21 of the main community facilities located in the urban area of the municipality, through spatial analyses developed with the Network Analyst extension of ArcGis® software.

To achieve this goal and because there was no organized geographic data of the municipality road network, available on-line public data was collected and an ArcMap file prepared for edition and correction of the road and urban public transport networks. Data entry operations on the population, bus schedules and location of the main community facilities were also carried out.

Regarding the geographic data, the road network was initially extracted from the Geofabrik platform and then corrected by cutting the polylines representing road links at every intersection, change of direction and exit. The network was also complemented with information on street name, road hierarchy (arterial, major collector, minor collector and access roads), average speed (defined as a function of road hierarchy: 70 km/h, 50km/h, 40km/h and 30 km/h), Elevation and Oneway fields. The urban public transport network was upgraded and corrected by cutting the polylines representing road links at every bus stop and by adding and average bus speed [10], Elevation and Oneway fields.

Official data on the territory delimitation of the municipality, civil parishes and statistic subsections (Statistics Portugal website), population (from Census 2011), Interurban Bus timetables (City Council) and the location of the main community facilities were also added into the GIS project.

Since the main community facilities are concentrated in the urban area of the municipality, three central urban zones were defined and considered in the analysis performed. The definition of these zones took into account the location of facilities in the territory, the topography of the urban zone (since it is a mountain town), the main road axes and the administrative territorial division (see Figure 1).

For each zone, a centroid representative of the convergent point of travelling made by the population was arbitrated:

- Centroid Zone 1: Covilhã Sports Complex, located in the lower part of the city, at an approximate level of 487m.
- Centroid Zone 2: Bus Station, located in the most recent zone of the city, at an approximate level of 547m.
- Centroid Zone 3: Underground Parking Park in the urban centre, at an approximate level of 676m.

It should be noted that between each centroid and the community facilities located in the respective zone, the travel time by private transport varies between 1 and 2 minutes.

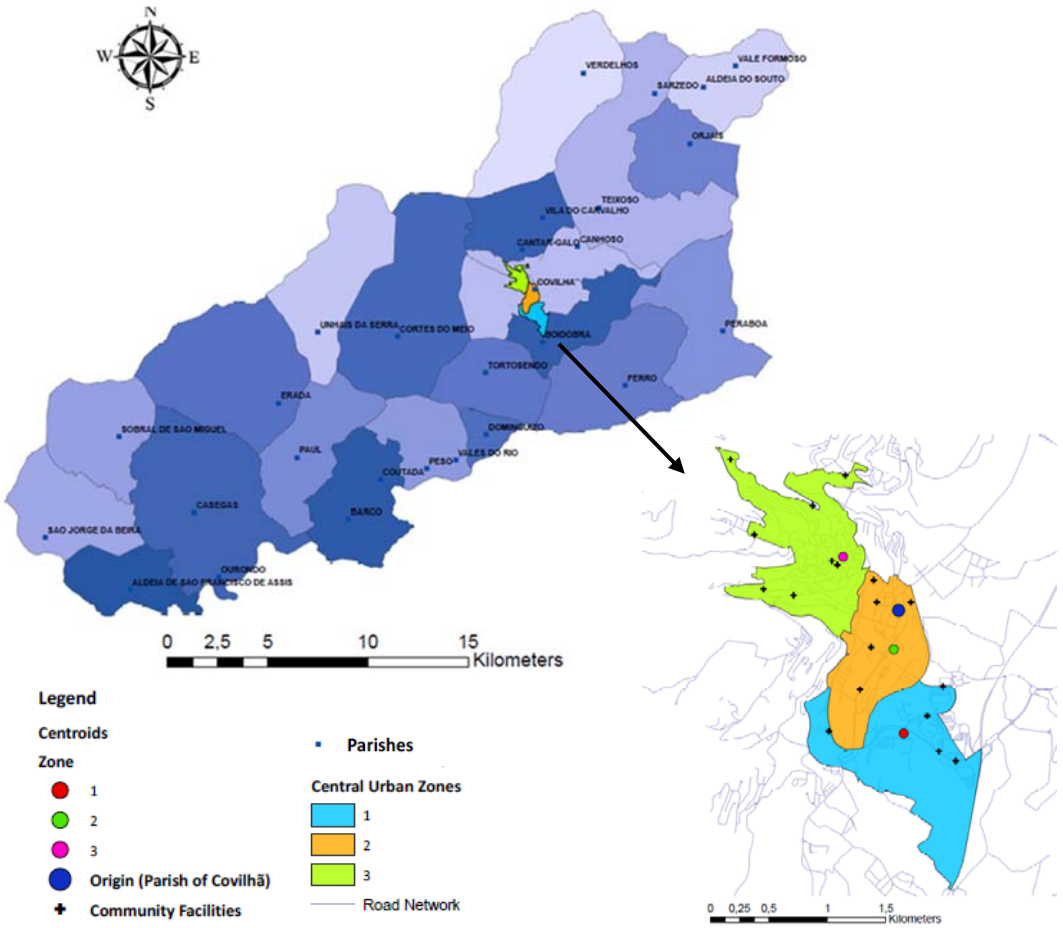

Figure 1. Location of the main community facilities of Covilhã municipality and delimitation of the central urban zones

3.3. Accessibility analysis

3.3.1. Accessibility by private transport

a) Analysis through isochrones and OD matrix of the accessibility for Covilhã's civil parishes: The first analysis determines time spent on a trip made by private transport from each civil parish to the main community facilities and to the remaining parishes of the municipality. In this analysis, 28 disaggregated civil parishes were considered (former administrative division of Covilhã territory) resulting in 28 maps of isochronous. The origin of the trips was considered in each parish council building. In the analyses to obtain the OD matrices, the origin of the trips was also considered in each parish council building, being the destinations the 3 centroids of the defined central urban zones. In Figure 2, it is possible to visualize one of the 28 isochronous maps obtained in the analysis, in this case, the one corresponding to the evaluation of the accessibility for the civil parish of Covilhã. The summary of times and distances between each civil parish and the centroids is presented in Table 1.

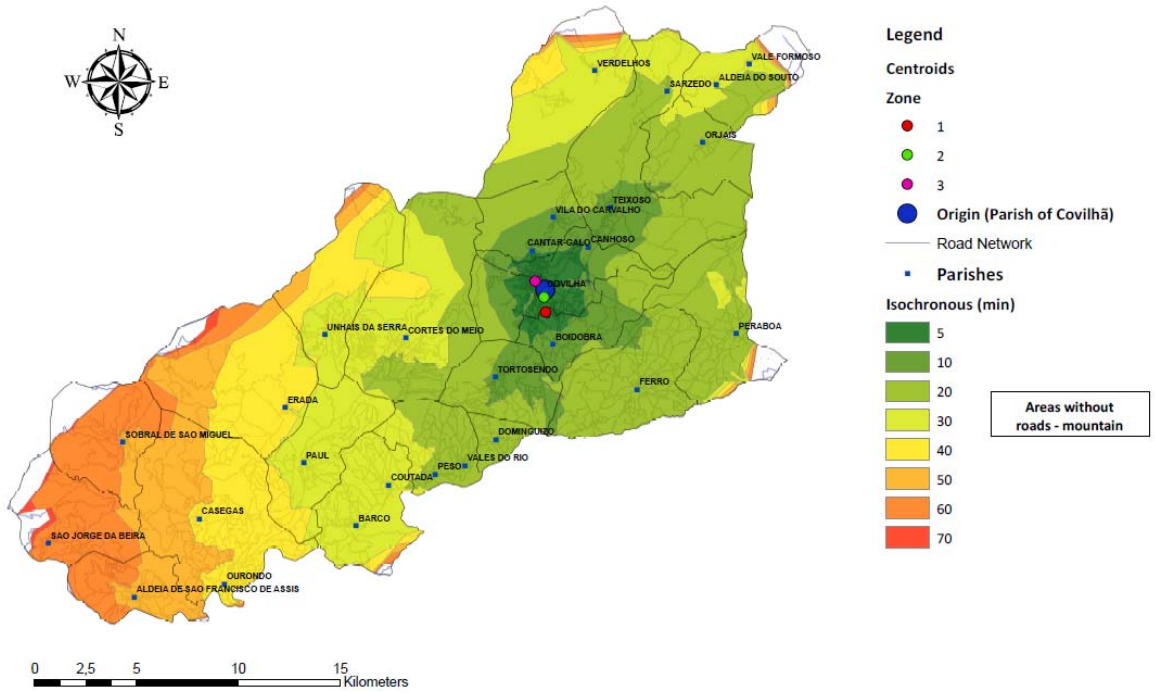

Figure 2. Accessibility by private transport between the civil parishes and the main community facilities of Covilhã [11]

b) Analysis of the territory and population served by the main community facilities through isochronous: This analysis evaluates the percentage of the population and territory covered for different travel times. For this purpose, an isochronous map from the centroid of Zone 2, located in the city Bus Station, was created. The Bus Station was chosen because it is a central point relating to the location of the considered community facilities and transport journeys. This analysis resulted in a set of polygons representing private transport travel times between 5 and 60 minutes. The percentage of population and territory for each of the isochrones was determined, as shown in Table 2.

3.3.2. Accessibility by public transport

a) Accessibility analysis of the civil parishes served by urban public transport and the Bus Station to the bus stops located next to the main community facilities of the municipality: This analysis evaluates the time spent on a trip, by urban public transport, from each civil parish covered by this type of transport to a central point of the city, and from that point, to the bus stop nearest to the referred community facilities. The urban public transport network was used in this analysis and an average traffic operating speed of 20 km/h, based on local data from 2014, was considered [10]. The Bus Station (centroid of central urban zone 2) was considered as the starting point of the isochronous analysis. The nearest stop to each community facility was also identified. Pedestrians travel along the road network at an average walking speed of 3 km/h [12–14], which reflects the difficulties of pedestrian mobility due to the orography of the city. The elevators and staircases located in the study area were not considered at this stage of the analysis, and are expected to be included in future analyses.

Table 1. Times and distances between each civil parish and the centroids of the urban zones, [11]

	Time (min)			Distance (km)		
Civil Parish	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 1**	**Zone 2**	**Zone 3**
Aldeia de São Francisco de Assis	46.2	47.2	48.5	33.6	34.2	35.0
Aldeia do Souto	18.7	20.0	21.5	14.8	14.4	15.2
Barco	22.7	23.6	24.9	17.9	18.1	18.9
Boidobra	3.8	5.5	3.5	2.8	3.7	2.2
Canhoso	5.8	5.5	6.7	5.1	3.8	4.7
Cantar-Galo	7.2	8.2	7.5	5.5	6.1	4.9
Casegas	37.2	38.1	39.4	26.3	26.9	27.7
Cortes do Meio	20.2	21.2	22.5	17.8	17.7	18.7
Coutada	19.9	20.9	22.2	17.5	17.2	18.2
Covilhã	2.4	0.6	2.4	1.8	0.4	1.6
Dominguizo	11.3	12.3	13.6	8.9	9.5	10.3
Erada	33.3	34.3	35.6	23.3	23.9	24.7
Ferro	12.8	13.7	15.9	11.4	12.0	12.8
Orjais	11.9	13.1	14.7	9.4	9.6	11.1
Ourondo	35.8	36.8	38.1	26.0	26.6	27.4
Paul	25.5	26.3	28.6	19.3	19.7	21.3
Peraboa	26.9	27.6	30.2	20.3	20.7	22.4
Peso	28.2	29.0	31.8	21.2	21.7	23.6
São Jorge da Beira	29.6	30.3	33.3	22.2	22.7	24.8
Sarzedo	30.9	31.7	34.9	23.2	23.7	25.9
Sobral de São Miguel	32.2	33.0	36.4	24.2	24.7	27.1
Teixoso	33.6	34.4	38.0	25.1	25.7	28.2
Tortosendo	34.9	35.7	39.6	26.1	26.7	29.4
Unhais da Serra	36.3	37.1	41.1	27.1	27.7	30.6
Vale Formoso	37.6	38.4	42.7	28.0	28.8	31.7
Vales do Rio	38.9	39.8	44.2	29.0	29.8	32.9
Verdelhos	40.3	41.1	45.8	30.0	30.8	34.0
Vila do Carvalho	41.6	42.5	47.4	30.9	31.8	35.2

Table 2. Number and percentage of the resident population and territorial area covered by private transport [11]

Isochronous (min)	**Inhabitants (n.º)**	**Inhabitants (%)**	**Area (km²)**	**Area (%)**
5	21963	42.4	36.7	6.6
10	36352	70.2	148.6	26.7
20	43148	83.3	333.7	60.1
30	49260	95.1	461.4	83.0
40	50050	96.6	499.9	90.0
50	50708	97.9	532.2	95.8
60	51797	100.0	555.6	100.0
Total	51797	100.0	555.6	100.0

As a result, an isochronous map for travel times between 5 and 50 minutes was obtained for trips made using the urban public transport, including the pedestrian component of the journey (Figure 3). Table 3 presents the travel times obtained between the Bus Station and the bus stop nearest to each community facility considered. Table 4 shows the travel times for trips made between the Bus Station and the Parish Councils building, also considering the pedestrian component.

b) Accessibility analyses of the civil parishes served by interurban public transport to the Bus Station: This analysis evaluates the time spent on interurban public transport trips between each civil parish and the main community facilities of the municipality. For this purpose, it was admitted that a passenger initially travels by interurban public transport to the city Bus Station and then by urban public transport to the community facilities. An example of the results obtained for the civil parish of Tortosendo is presented in Table 5. The times presented in this table correspond to the sum of travel times made by interurban and urban public transport.

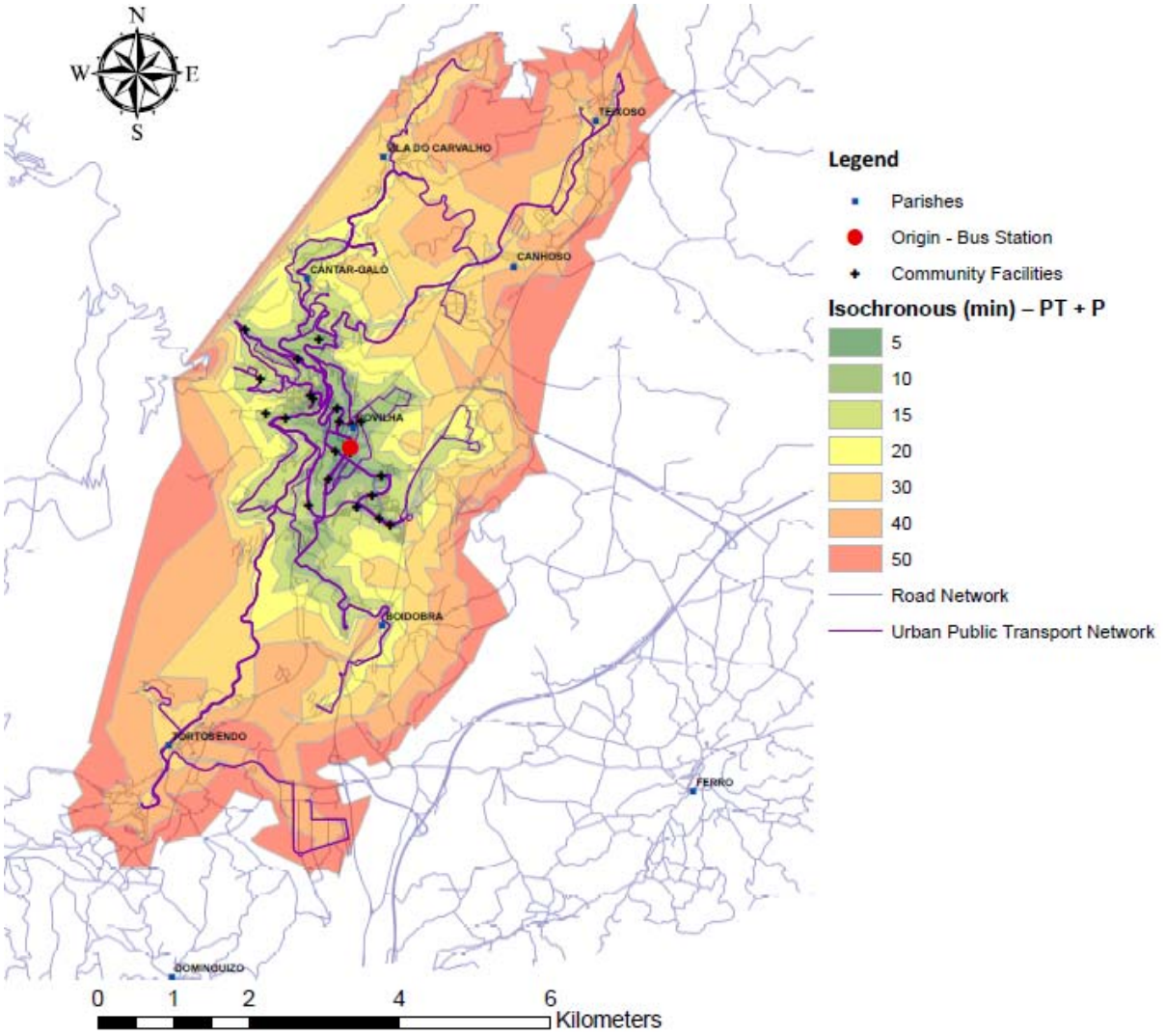

Figure 3. Accessibility by urban public transport to the main community facilities of Covilhã [11]

Table 3. Travel times for trips made by urban public transport between the Bus Station and the nearest bus stops of the main community facilities of Covilhã [11]

Origin	Community Facility	Bus Stop (name)	Time (min)
Bus Station	Central de Camionagem (Bus Station)	C. Camionagem	0.0
	Serra Shopping (Shopping Center)	Serra Shopping	2.0
	Escola Secundária Quinta das Palmeiras (High School)	Escola das Palmeiras	2.0
	Intermarché (Supermarket)	Intermarché Ascendente	2.1
	UBI: Faculdade Ciências da Saúde (University: Faculty of Health Sciences)	Faculdade Medicina	3.6
	Escola Secundária Frei Heitor Pinto (High School)	Terminal 2	3.8
	Estação Ferroviária (Train Station)	Estação	4.2
	Complexo Desportivo da Covilhã (Sport Complex)	Hotel Turismo	4.6
	Escola Secundária Campos Melo (Hight School)	Esc. Frei H. Pinto	4.8
	Tribunal (Court)	C. Comercial Estacão	5.1
	Centro de Saúde (Health Center)	Centro de Saúde	5.3
	Finanças (Tax Services)	Finanças	6.0
	Centro Hospital da Cova da Beira (Hospital)	Hospital	6.3
	UBI: Polo principal e Faculdade de Engenharia (University: Faculty of Engineering)	UBI	6.6
	UBI: Faculdade de Ciências Sociais e Humanas (University: Faculty of Social and Human Sciences)	Polo IV	8.7
	Estádio José Santos Pinto (Football Stadium)	Grupo da Mata	10.6
	Piscina Municipal (Municipal Swimming Pool)	Igreja Penedos Altos	10.8
	Câmara Municipal da Covilhã e CTT (City Hall and Post Office)	Pelourinho	11.7

Note: Table 3 includes all the urban public routes between the Bus Station and the main community facilities considered, however, for distances less than 500 m, pedestrian movement can be considered more attractive.

Table 4. Travel times between the Bus Station and the Parish Council buildings by urban public transport considering the pedestrian component [11]

Origin	Destination Parish Council building	Time (min) Urban Public Transport + Walking
Bus Station	Covilhã	5.4
	Cantar-Galo	14.3
	Boidobra	16.0
	Vila do Carvalho	24.7
	Tortosendo	25.6
	Canhoso	30.7
	Teixoso	31.2

Table 5. Travel times between the civil parish of Tortosendo and the main community facilities, by public transport [11]

Origin: Tortosendo **Community Facility**	**Time (min)** **Interurban + Urban Public Transport**
Central de Camionagem (Bus Station)	14.1
Serra Shopping (Shopping Center)	16.1
Escola Secundária Quinta das Palmeiras (High School)	16.1
Intermarché (Supermarket)	16.2
UBI: Faculdade Ciências da Saúde (University: Faculty of Health Sciences)	17.7
Escola Secundária Frei Heitor Pinto (High School)	17.9
Estação Ferroviária (Train Station)	18.3
Complexo Desportivo da Covilhã (Sport Complex)	18.8
Escola Secundária Campos Melo (High School)	19.0
Tribunal (Court)	19.2
Centro de Saúde (Health Center)	19.5
Finanças (Tax Services)	20.2
Centro Hospital da Cova da Beira (Hospital)	20.4
UBI: Polo principal e Faculdade de Engenharia (University: Faculty of Engineering)	20.7
UBI: Faculdade de Ciências Sociais e Humanas (University: Faculty of Social and Human Sciences)	22.9
Estádio José Santos Pinto (Football Stadium)	24.7
Piscina Municipal (Municipal Swimming Pool)	24.9
Câmara Municipal da Covilhã e CTT (City Hall and Post Office)	25.9

4. Main results and conclusions

The main results of this work consider the preparation of a medium-sized city road network with publicly available data for assessments of accessibility using GIS and an initial evaluation of the accessibility conditions to a set of 21 community facilities by private and public transport using the Network Analyst extension of ArcGis®.

With regard to the case study and private transport, it is possible to verify that the trips made between the parish council buildings and the main community facilities of the municipality present an average travel time of approximately 22 minutes (standard deviation equal to 13,7 minutes), with an average travel distance of 16 km (standard deviation equal to 9,5 km). São Jorge da Beira is the civil parish of Covilhã with the longest travel distance, corresponding to a travel time of 55 minutes. The average speed of traffic obtained was around 45 km/h, value between the speeds assigned to major (50 km/h) and minor (40 km/h) collector roads. This speed value can be considered an indicator that most civil parishes are

served by roads of this hierarchy class. Approximately 70% of the municipality population lives in areas with less than 10 minutes of travel time to the Bus Station. 30 minutes will cover almost all of the residents (95,1%) and a territory area of 83.0%. These values can be considered as an indicator of good accessibility by comparison with the 30 minute time-based approach adopted in several national and international studies of accessibility to health services located in major cities and metropolitan areas [15]. Regarding the urban public transport, considering the sum of the urban transport and walking components, travel times shorter than 12 minutes were obtained for trips between the Bus Station and the bus stops located next to the main community facilities. Civil parish served by the urban public transport presented travel times to the Bus Station between 5 to 31 minutes. Within the urban perimeter, the most distant location covered by the urban public transport service presents a 50 minute travel time from the Bus Station. From the results obtained, it is still possible to verify that accessibility by interurban public transport is reduced for the peripheral parishes of the municipality, presenting high travel times (maximum of 117 minutes and on average 50 minutes) and low frequencies of transport, both on weekdays and weekends.

As future work, new analyses incorporating the orography of the municipality, the waiting time for public transport, elevators and stairways in the walking component and peak periods, are suggested.

References

[1] "European Urban Mobility Policy Context EUROPEAN COMMISSION," 2017.
[2] K. T. Geurs and B. van Wee, "Accessibility evaluation of land-use and transport strategies: Review and research directions," *J. Transp. Geogr.*, 2004.
[3] L. Bertolini, F. le Clercq, and L. Kapoen, "Sustainable accessibility: A conceptual framework to integrate transport and land use plan-making. Two test-applications in the Netherlands and a reflection on the way forward," *Transp. Policy*, 2005.
[4] A. Ford, S. Barr, R. Dawson, and P. James, "Transport Accessibility Analysis Using GIS: Assessing Sustainable Transport in London," *ISPRS Int. J. Geo-Information*, 2015.
[5] P. Bolstad, *GIS Fundamentals: A First Text on Geographic Information Systems*. 2016.
[6] S. Liu and X. Zhu, "An Integrated GIS Approach to Accessibility Analysis," *Trans. GIS*, 2004.
[7] C. Jacobs-Crisioni, F. Batista e Silva, C. Lavalle, C. Baranzelli, A. Barbosa, and C. Perpiña Castillo, "Accessibility and territorial cohesion in a case of transport infrastructure improvements with changing population distributions," *Eur. Transp. Res. Rev.*, 2016.
[8] A. Domènech and A. Gutiérrez, "A GIS-Based Evaluation of the Effectiveness and Spatial Coverage of Public Transport Networks in Tourist Destinations," *ISPRS Int. J. Geo-Information*, 2017.
[9] Fundação Francisco Manuel dos Santos, "PORDATA," 2016. [Online]. Available: http://www.pordata.pt/Municipios.
[10] B. Martins, "Avaliação e implementação de um serviço de informação ao cliente em cidades de média dimensão: Caso de estudo da Covilhã/Covibus - Evaluation and implementation of a customer information service in medium-sized cities: Covilhã / Covibus case study," University of Beira Interior, 2014 (in Portuguese).
[11] A. Tomé, Evaluation of Accessibilities in Covilhã Municipality using GIS,University of Beira Interior, 2016 (in Portuguese).
[12] EPFL, "Cahier TEA 8 – Les Voiries Urbaines," Lausanne, 1995.
[13] Austroads, "Pedestrians," in *Guide to Traffic Engineering Practice*, Sydney, 1995.
[14] HCM, *Highway capacity manual 2010*. 2010.
[15] G. Borruso, S. Bertazzon, A. Favretto, B. Murgante, and C. Torre, *Geographic Information Analysis for Sustainable Development and Economic Planning: New Technologies (Advances in Geospatial Technologies)*, 1rd editio. Information Science Reference, 2013.