Public transportation and accessibility to education centers in Maldonado, Uruguay

Renzo Massobrio, Sergio Nesmachnow, Emiliano Gómez,
Facundo Sosa, and Silvina Hipogrosso

Universidad de la República, Uruguay

Abstract. This article presents a study of public transportation and accessibility to public services in Maldonado, Uruguay. Accessibility is a crucial concept in nowadays smart cities, to guarantee a proper mobility, citizen participation in social, economic, and cultural activities, and an overall good quality of life. Several data sources are studied and processed to characterize the accessibility provided by the public transportation system of Maldonado to public services, specifically to education centers. A matrix of travel times by public transportation is computed and used to define a flexible accessibility indicator to reach destinations of interest. Finally, an interactive visualization tool is developed to graphically display the computed information. The accessibility indicator constitutes an input for the decision-making of the transportation authorities of the studied area, as well as it allows identifying potential inequity situations.

Keywords: smart cities, mobility, public transportation, accessibility, public services

1 Introduction

The characterization of urban accessibility is an important tool to determine the quality of transportation systems and their impact on the daily activities of citizens [5]. Several recent researches have studied different aspects of accessibility, e.g., regarding urban public facility spaces [13], urban planning [3], neighborhood retail [15], and other relevant issues.

Evaluating accessibility is a challenging task, even considering a simple definition of accessibility, related to the capability of reaching certain relevant destinations in the city. The challenges are consequence of the plethora of theoretical concepts to be considered (including land utilization, universal access, transportation modes, etc.), and also the lack of sound methodologies for empirical evaluation. Thus, accessibility is often considered as a poorly understood concept, which is not correctly evaluated, and rarely taken into account for elaborating polices for urban development, transportation design and operation, infrastructure investments, and other relevant actions for improving quality of life. Overall, knowledge about accessibility is very useful for assisting policymakers and planners to evaluate different approaches to develop transportation with a special focus on inequities and phenomena with high social impact.

This article presents a characterization of public transportation and accessibility to education centers in the metropolitan area of Maldonado, Uruguay. The case study is an important urban conglomeration in the Southeast of Uruguay, with more than 135.000 inhabitants. The proposed research focuses on public transportation, as it is understood to be the most efficient, sustainable, and socially fair transportation mode [4]. The distances and total travel times between different zones by using public transportation are studied via a data analysis approach [17] to identify areas with poor mobility provision that imply high travel times, and therefore impose restrictions on territorial accessibility.

In order to quantify the provision of the transportation system in the Maldonado metropolitan area, a matrix of travel times between different areas of the city is computed. Trips in different modes (walking, with a direct bus line, and trips involving transfers) are considered. Then, geolocated data about public services is used to compute the accessibility offered by the public transportation system. As a case study, the accessibility to education centers is computed, as it is a relevant public service for the Municipality of Maldonado. By incorporating the scope of different mobility options, the proposed methodology advances on a factor for the definition of indicators of inequity in intra-urban accessibility and their subsequent use for support and decision-making on urban planning.

The main contributions of the reported research include: i) a matrix of travel times on public transportation in the Maldonado metropolitan area, at the census segment level; ii) an accessibility indicator by public transportation to education centers located in the studied area; and iii) a web visualization tool that allows graphically displaying the accessibility indicator. The reported results are useful for transit and transportation authorities of the Municipality of Maldonado, since they constitute an important input when defining public policies, designing new transportation lines, or redesigning current ones in order to serve identified areas as of poor accessibility.

The article is organized as follows. Section 2 reviews relevant concepts and related works about accessibility and related initiatives in Uruguay. The proposed data analysis approach and the case study are described in Section 3. The implementation details are presented in Section 4, including the calculation of the matrix of travel times for public transportation and the accessibility indicator to education centers. The results of the analysis are shown and discussed in Section 5 along with a brief description of the web visualization tool. Finally, Section 6 presents the main conclusions and lines for future work.

2 Accessibility and related works

Citizen participation in social, economic, and cultural activities requires people to travel, sometimes long distances and involving long periods of time [8]. The ability of individuals to overcome limitations imposed by distances and other mobility-related difficulties is critical when actively participating in city life [2]. This measure of the ability of transportation systems to allow individuals to overcome distances is known under the concept of accessibility.

The term accessibility has been extensively studied in the literature, with the first definitions emerging from the area of geographical studies more than 60 years ago [6]. Although the term is widely disseminated, there are multiple (and complementary) definitions, which vary according to the area of study and the point of view from which its quantification is proposed. Generally speaking, accessibility can be defined as a measure of the effort (or ease) of overcoming spatial separation. Specifically, accessibility seeks to measure the spatial distribution of opportunities (e.g., jobs, study sites, hospitals) adjusted for people's ability or desire to overcome separation (e.g., distance, time, cost) to such opportunities. Within the classification established by Ingram [14], this project focuses on comprehensive accessibility, which contemplates the degree of interconnection of a point or area with all the others on the same surface.

Several indicators have been proposed to measure the separation between points/areas when evaluating accessibility, among them, travel time is one of the most intuitive, as it is strongly related to the perception of users of a transportation system. Lei and Church [16] presented a review on the use of travel time when quantifying the accessibility offered by public transportation systems. The authors show that various works in the literature focus on the physical characteristics offered by transportation systems (e.g., distance to the bus stop) rather than focusing on travel time. Furthermore, within the works that do focus on travel time, there are a number of assumptions that significantly affect the final measure, including considering fixed waiting and transfer times or a constant speed for vehicles. Salonen and Toivone [19] presented a comparison of different techniques for estimating travel times, both for private and public transport. The authors evaluated different travel time estimation models on a case study in the capital region of Finland. The results achieved show that those models that incorporate a greater amount of information regarding the transportation system are able to estimate travel times with greater precision, although the differences between models were less in the downtown areas.

In Uruguay, some studies have addressed the issue of accessibility, particularly using public transportation. Hansz [7] studied the disparity between public transportation supply and transportation needs in Montevideo. The author defined a public transportation provision index that combines the frequency of buses and the number of stops in a given area. The provision offered by the Montevideo public transportation system, measured according to this index, is strongly biased towards the city center. Hernández [9] studied inequities in access to employment and educational opportunities between different social classes as a consequence of the offer of public transport. This work used the travel time to compute accessibility, which was obtained through How to Go, a web application offered by the Municipality of Montevideo to estimate travel times by public transport. The study showed that there is an unequal distribution of mobility opportunities, particularly for access to job opportunities and access to higher level education. Later, Hernández et al. [10] built a matrix of travel times using theoretical timetables of buses in Montevideo, which was used as input to generate an index of accessibility to job opportunities in the city.

Other research efforts developed within our research group include the socio-economic analysis of the transportation system in Montevideo using big data and distributed computing [18], the analysis of sustainable transportation initiatives in Montevideo [12] evaluating the accessibility index proposed by the World Business Council for Sustainable Development [20], and the empirical study performed in Parque Rodó neighborhood using face-to-face surveys [11].

3 Case study and data analysis approach

This section describes the studied area and the methodology applied for data analysis to characterize accessibility.

3.1 Maldonado metropolitan area

The metropolitan area of Maldonado includes the conurbation of the cities of Maldonado and Punta del Este, which progressively joined, including transportation routes. Maldonado is the administrative capital of the department and Punta del Este is considered the tourist capital at national level. The city of San Carlos is considered as part of this conurbation, although Maldonado and San Carlos are separated by a suburban space. These three cities are the arteries of an urban network that extends even west to Portezuelo and east to José Ignacio. The suburban area has specific mobility needs and the demand for public transportation, and currently has problems with traffic congestion and accessibility to important points. In addition, the cities of Piriápolis and Pan de Azúcar are less than 30 km from Maldonado and public transportation lines connect them frequently. More than 150.000 people live in the studied area, while about 20.000 live in Piriápolis and Pan de Azúcar.

Fig. 1: Metropolitan area of Maldonado

3.2 Data analysis approach

The Municipality of Maldonado granted access to a set of public transportation data, including lines, stops, and timetables of the different routes. Each dataset has specific features, which are described in the following paragraphs.

Bus lines and stops. This dataset includes the layout of routes lines and the location of the bus stops of the public transportation system. From a geographical point of view, the main difficulty with these data lies in the fact that the dataset of lines and stops are independent. Fig. 2 shows the set of stops and lines of the public transportation system, according to the provided data.

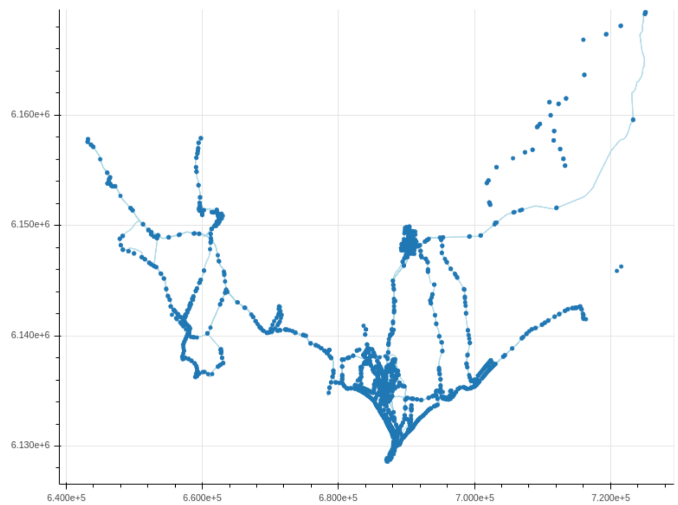


Fig. 2: Bus lines and stops of the public transportation system in Maldonado

Certain problems and particularities of the studied datasets pose challenges for building a matrix of travel times for public transportation to compute the accessibility indicator. Three main problems were identified: stops located in places without defined bus lines; stops located very close to each other (which clearly correspond to the same physical stop); and stops that do not coincide with the layout of the bus lines. This last point is the most challenging, since there is no direct association that indicates to which line(s) a certain stop corresponds.

An automated process was implemented to solve the aforementioned problems applying geospatial operations to associate lines and stops. The algorithm works as follows: i) for each bus line a *buffer* operation is performed to convert the line to a 10m wide polygon; ii) the polygon is intersected with the stop layer to obtain stops that are less than 10 m from the line; and iii) the set of stops is traversed according to the direction of the line and consecutive stops that are less than 50 m from each other are eliminated, on the understanding that it is the same physical stop. Fig. 3 shows the implemented correction process (stops in the original set are marked in red and the stops after applying the correction procedure are marked in green).

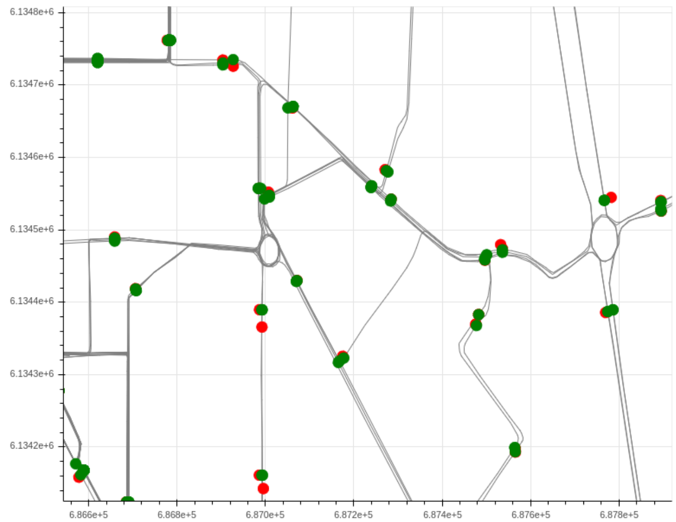


Fig. 3: Bus stop correction (red–original bus stops; green–corrected bus stops)

Timetables and trip times. The other provided dataset corresponds to the timetables of the different lines of the public transportation system. The data are separated according to the transportation company that operates the service. The provided dataset consist of Excel files that do not follow a standardized format, which makes its automated processing extremely difficult. Since it does not account for a large volume of data, the processing was carried out manually. For each line, departure times and passing times for some notable points along the route are reported. These notable points are identified by a name that does not necessarily match the name defined in the transportation system. Therefore, the procedure involved associating these points with their corresponding stops and associating the average travel time from the start of the route to that stop, based on the published timetables. Finally, for the rest of the stops on the line, travel times are interpolated from the known travel times.

Since the information of lines and stops is separated from the data of the timetables, there are differences between both datasets. In particular, timetable information is not available for a few lines (line 32 from Pan de Azúcar to Nueva Carrara, line 62 from/to Punta del Este, line 25 from San Carlos to José Ignacio, line 26 from Garzón to San Carlos, line 27 of Guscapar company, and direct line Punta del Este–San Carlos). In these cases, it is not possible to know the travel times between the stops on the route and, therefore, they were not considered within the model. Other lines were partially included in the model, according to the available data: e.g., line 34 from Las Flores (and not from Pan de Azúcar) to Piriápolis, line 55 from Manatiales (and not Buenos Aires) to Maldonado, and line 62 between Maldonado and La Capuera (and not from/to Punta del Este).

Overall, a total number of 66 lines/variants operated by six companies were included in the developed model.

4 Accessibility to education centers

This section describes the methodology for computing the proposed accessibility indicator to education centers, describing the studied area and the two needed inputs: the matrix of travel times and the location of education centers.

4.1 Definition of the studied area

The basic unit of the analysis is the census segment, defined by the National Institute of Statistics (INE). The file published by INE was corrected, since it had some invalid geometries that prevented the correct data processing.

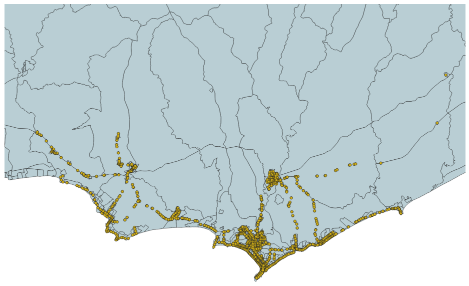
The process used to define the studied area is graphically described in Fig. 4 and commented next. Initially, all census segments that have at least one stop of the transportation system within the polygon that defines them are considered (Figures 4a–4b). Then, neighboring towns that do not have stops are considered to avoid gaps in the studied area, computing the convex hull of the set of census segments (Fig. 4c) and intersecting with the total of census segments (Fig. 4d) to obtain all census segments to consider. The centroid of each census segment in the resulting set is computed, assuming that all trips from/to a certain segment begin (or end) at the centroid of that segment (Fig. 4e).

4.2 Matrix of travel times

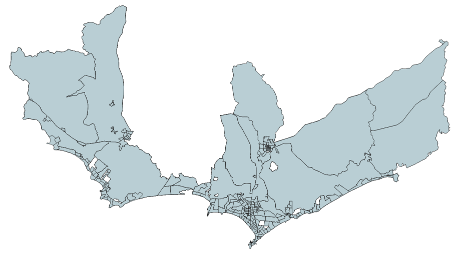
The matrix of travel times for public transportation was built considering trips with up two legs (one transfer). Travel times include: i) the walking time from the centroid of the origin segment to the first bus stop; ii) the walking time from the descent stop of the last bus of the trip to the centroid of the destination segment; iii) the walking time between stops on those trips that involve transfers; and iv) the time traveling on each bus involved in the trip. Also, direct walks (up to 30 minutes) are considered between nearby centroids, since walking can be a more attractive option than public transportation. Walks from the origin centroids to the first bus stop and from the last bus stop to the destination centroids are limited to 30 minutes. Walks between transfer stops are limited to 20 minutes. The fastest travel connecting a pair of centroids is considered, assuming that people make optimal decisions to move within the city, within the rules imposed in the model regarding maximum walks and number of transfers allowed.

A directed and weighted multigraph is constructed to build the matrix. Nodes of the graph represent the centroids of census segments and the bus stops. Nodes can be connected by more than one edge. The weight of each edge represents the travel time between nodes (walking or by bus). A shorter path algorithm is applied to compute the fastest travel time between each pair of centroids.

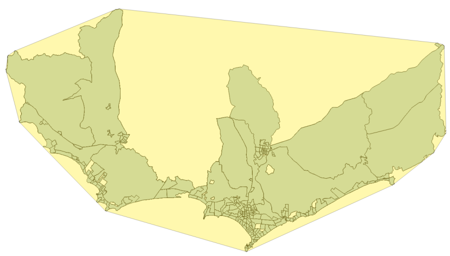
Walking times between centroids, between centroids and stops, and between stops, are computed on the road network of the city. Each centroid/stop is moved to the nearest road and times are computed using Open Source Routing Machine, an engine implemented in C++ that combines routing algorithms with OpenStreetMap road network data to efficiently compute shorter paths. The `table`



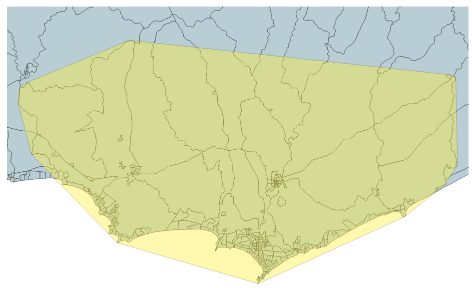
(a) Census segments and stops



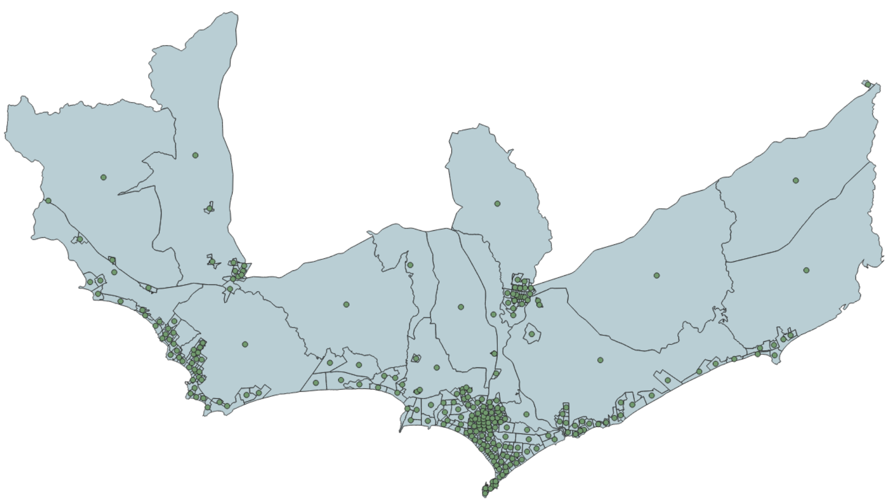
(b) Census segments with at least one stop



(c) Convex hull of the set



(d) Intersection with census segments



(e) Final set: census segments and their centroids

Fig. 4: Process for defining the studied area

method was used to compute the travel times between pairs in a list of geographic coordinates, using the average speed for each type of road and traffic rules imposes in the `foot.lua` profile. Routes for a small subset of 41 nodes cannot be computed using this approach, as they were located in areas far from the road network. The travel times to/from these nodes was computed using the geographical distance and a walking speed of 5 km/h.

Bus travel edges are weighted according to the average travel time between the nodes they connect. To ensure that the shortest path does not have more than one transfer, two different nodes are used to represent each centroid (one when the centroid acts as the origin and the other when it acts as the destination) and four to represent each physical stop (which represent the stop when it is the origin or destination of the first or second trip within the total route). Origin centroids have only outgoing edges, while destination centroids have only inward edges. This allows routes to be modeled with a direct trip and even with a transfer, considering the walk between stops in the eventual transfer. A penalty of 15 minutes (added to the weight of the walking edges that connect stops) is considered on those roads that involve a transfer.

The NetworkX library of Python was used to represent the graph and compute the shortest paths. The generated graph includes a total number of 6382 nodes ($253{\times}2$ centroids $+$ $1469{\times}4$ stops) and 642 775 edges.

4.3 Location of education centers

The geographical location of education centers (initial, primary, secondary, and technical-professional education) are obtained from the Open Data Catalog [1]. Fig. 5 shows the location of these centers in the studied area.

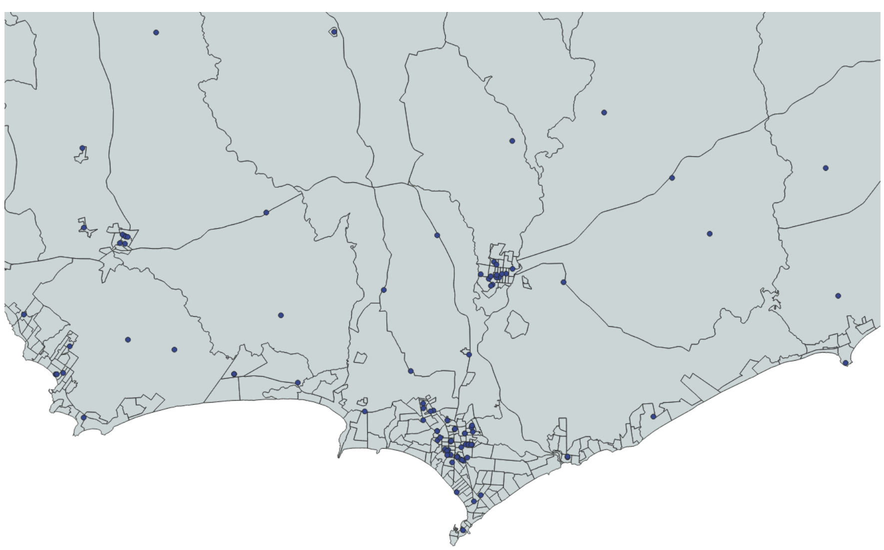


Fig. 5: Education centers in the metropolitan area of Maldonado

4.4 Accessibility indicator

The matrix of travel times and the location of the education centers are used as input to compute the accessibility indicator to education centers by public transportation, using census segments as unit. The proposed indicator is based on the notion of accumulated opportunities, originally proposed by Hansen [6]. The method consists of characterizing the accessibility of every census segment by adding all education centers that are reachable from it, traveling for up to m minutes by public transportation. The threshold m is parameterizable, allowing to perform the accessibility study under different conditions. The proposed indicator is flexible, since it allows varying the travel time threshold, and can even be used to evaluate accessibility to other opportunities, provided that geolocated information of their location is available. An improved version of the proposed indicator could consider the opening hours of each education center computing the value for each hour of the day. However, opening hours is not included in the open dataset used in this study. The proposed indicator can be extended to contemplate the time dimension, if this information is published in the future.

5 Results and discussion

This section reports the main results achieved and presents the web tool developed to display the accessibility indicator.

5.1 Travel time matrix

The computed matrix of travel times for Maldonado metropolitan area is is publicly available in CSV format at `www.fing.edu.uy/~renzom/TTM.csv`, The corresponding entry for or each pair of census segments reports the travel time using public transportation, in minutes. The matrix is a relevant result in itself, since it is an important input to address various types of design and optimization problems related to public transportation in the studied area.

The matrix has dimension 253×253. According to the implemented model, the travel time reflected in the matrix is the fastest option that connects each pair of census segments, considering direct walks, direct bus trips or even a transfer. Transfer trips add 15 minutes to walk between stops, transfer walks are limited to 20 minnutes, and direct walks between centroids and entrance/exit to the transportation network are limited to 30 minutes. For this reason, some segments are disconnected, either due to the absence of lines connecting it with up to a transfer or because the stops are at a distance from the centroid that exceeds the limit allowed for walks. The results show that 13 021 origin-destination pairs (out of 64 009) are disconnected.

The average travel time between all pairs of connected census segments is 52.5 minutes. Fig. 6 shows a histogram with the frequency of each travel time value (in minutes), considering the total number of connected census segments. Regarding travel modes, 58.1% of the trips correspond to direct trips involving a single bus, 40.5% correspond to trips with a transfer, and 1.4% correspond to direct walks, without using the public transportation system.

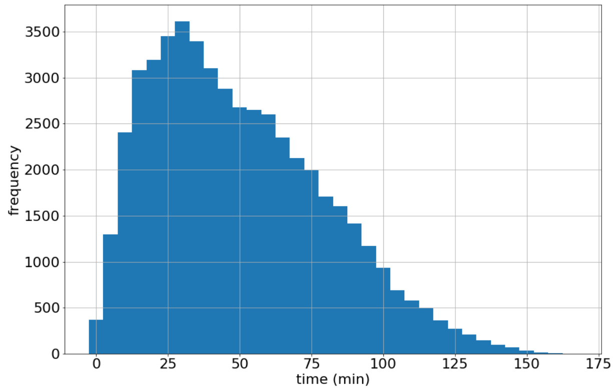


Fig. 6: Histogram with the frequency of travel times between census segments

5.2 Accessibility indicator

The accessibility indicator combines the matrix of travel times and the location of education centers. By definition, each census segment accesses all education centers in it and in census segments that can be accessed by public transportation on trips of up to m minutes. By varying the parameter m it is possible to study different situations, based on different assumptions. Using $m = 0$, each census segment only accesses the education centers that are located within the polygon that defines them. In the choropleth map in Fig. 7, the color of each segment indicates the percentage of education centers it contains, with respect to the total number of centers available. The figure shows that the rural census segments (those with the largest area) are mostly covered by at least one education center.

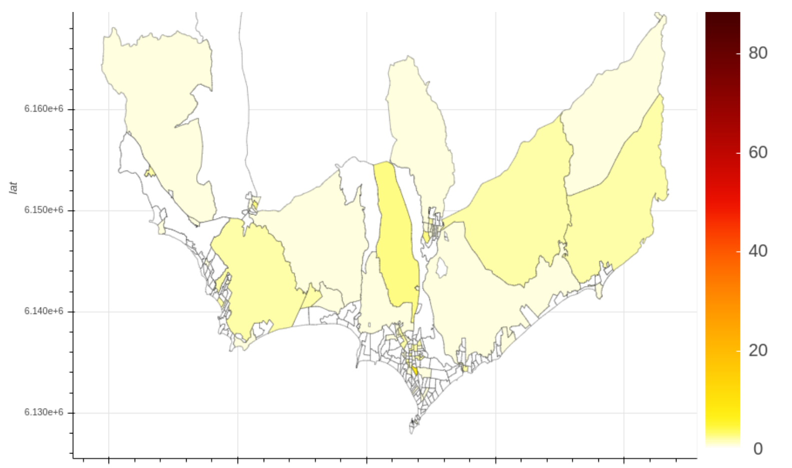


Fig. 7: Percentage of education centers located in each census segment

The accessibility of different scenarios can be studied varying the threshold m. Fig. 8 shows the accessibility indicator for $m = 10$ minutes. Results indicate that a small change in the threshold m implies a significant change on the spatial distribution of the accessibility indicator. The census segments located in the central areas of Maldonado and San Carlos show higher accessibility values than the large census segments of the rural periphery. This effect occurs because census segments without an education center can access one in a neighboring segment through public transportation trips or short walks.

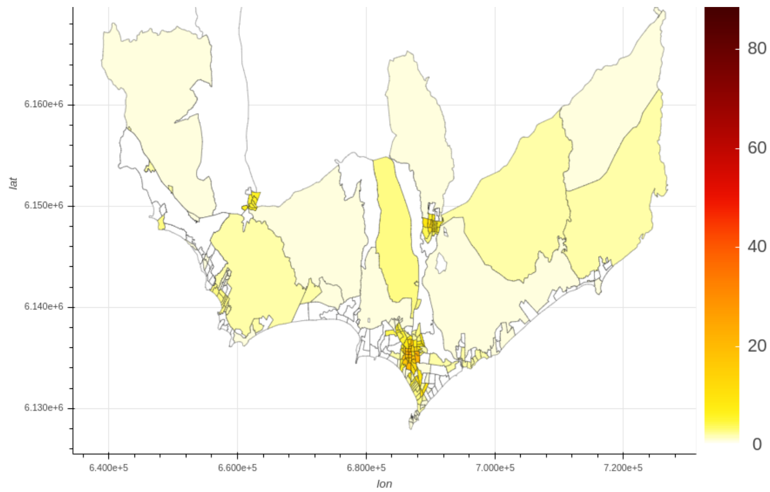


Fig. 8: Percentage of accessible education centers traveling up to 10 minutes

The coastal areas of Punta Ballena, Pinares, and Punta del Este still have low accessibility with low time thresholds. This phenomenon change when a slightly higher threshold is set. Fig. 9 shows the accessibility indicator with up to 20 minutes of travel ($m = 20$). In addition, accessibility continues improving both from the center of Maldonado and from San Carlos. In turn, it is observed that the coastal areas to the east (e.g., San Rafael, La Barra) present low accessibility indices when considering trips of up to 20 minutes.

Finally, Fig. 10 shows the accessibility indicator using a 40-minute threshold. In this case, good accessibility exists in most urban census segments. However, there is a clear stagnation in terms of accessibility in most rural segments, which only access to centers located in them and fail to access to centers in other areas. Likewise, an inequality phenomenon is observed in the coastal census segments, where the segments to the west of Punta del Este have better accessibility values than those located to the east of the peninsula.

5.3 Web visualization tool

A web visualization tool was developed to present the results of the accessibility indicator in a friendly and interactive way. The tool is publicly available at `www.fing.edu.uy/~renzom/acc_maldonado`. The tool shows the studied area on an interactive map, at the census segment level. The map has tools to zoom, scroll, and download the current image. A slider bar is provided to allow configuring the time threshold m considered for computing the accessibility index.

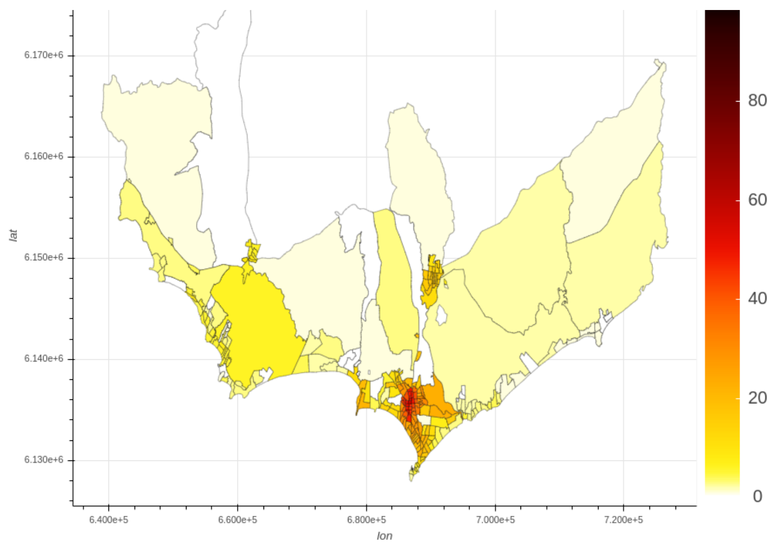


Fig. 9: Percentage of accessible education centers traveling up to 20 minutes

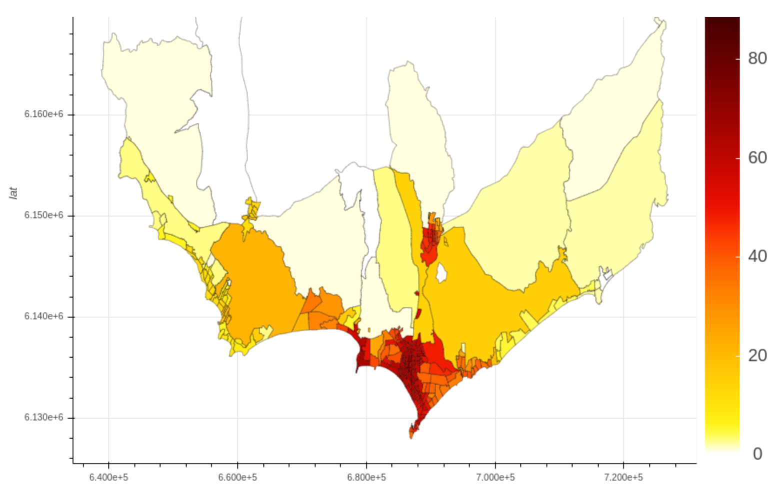


Fig. 10: Percentage of accessible education centers traveling up to 40 minutes

Once a threshold is set, the map is updated to report the accessibility indicator to education centers. The result is shown through a choropleth map where each census segment is assigned a color based on its accessibility indicator value (Fig. **??**). Positioning the cursor on a specific census segment displays the code that identifies the census segment, the name of the city, the number of education centers reached, and the percentage of the total that they represent.

6 Conclusions and future work

This article presented a study of the accessibility to public services in Maldonado, Uruguay, when using the public transportation system. In order to compute an accessibility index a travel time matrix for the public transportation was built using open datasets and data provided by the local authorities, including bus lines, bus stops, and timetable information. With these data the public transportation was modeled as a graph, accounting for every alternative to connect origin and destination pairs in the studied scenario. A shortest-path algorithm was executed over this graph to compute the fastest travel time between each origin and destination. Computed travel times include walking times to/from the bus stop and in-vehicle time of both direct trips and multi-leg trips involving up to one bus transfer. The computed travel time matrix is publicly available and is a highly useful resource for authorities and researchers alike.

Then, the accessibility to education was studied combining the computed travel time matrix with the location of education centers in the studied area. Following the usual methodology in the field, accessibility was measured accumulating the opportunities (i.e., centers) that can be reached from a given origin when traveling up to a certain threshold of time via public transportation. An interactive web application was developed that outlines the accessibility measures of the studied zone when varying the travel time threshold. The application shows a map of the area and colors different zones according to their accessibility to education centers.

According to our review of the related works, this research is one of the first steps of studying the public transportation system of Maldonado, Uruguay. The results of this research (i.e., the travel time matrix, accessibility indicator, and web application) are valuable to transport and urban planning authorities and research interested in improving the public transport accessibility in the area.

The main lines of future work involve feeding the model with richer information including: up-to-date GPS bus location data, ticket-sale data from on-board smartcard readers present in the buses of the system, as well as historic passenger information to improve the travel time estimations and make recommendations to improve the quality of service of neglected areas with significant inequalities.

References

1. Administración Nacional de Educación Pública: Centros anep. Disponible en línea: https://catalogodatos.gub.uy/dataset/anep-centros-anep [12/2019] (2019)

2. Cardozo, O., Rey, C.: La vulnerabilidad en la movilidad urbana: aportes teóricos y metodológicos. In: Aportes conceptuales y empíricos de la vulnerabilidad global, pp. 398–423. Resistencia, Chaco: EUDENE (2007)
3. Duranton, G., Guerra, E.: Developing a common narrative on urban accessibility: An urban planning perspective. Tech. rep., Brookings, Moving to Access (2016)
4. Grava, S.: Urban Transportation Systems. McGraw-Hill Education (2002)
5. Hansen, H.: Analysing the role of accessibility in contemporary urban development. In: Computational Science and Its Applications, pp. 385–396. Springer Berlin Heidelberg (2009)
6. Hansen, W.: How accessibility shapes land use. Journal of the American Institute of Planners 25(2), 73–76 (1959)
7. Hansz, M.: Analysis of the spatial disparity in transport social needs and public transport provision in Montevideo. Master's thesis, University of Leeds (2016)
8. Harvey, D.: Social justice, postmodernism and the city. International Journal of Urban and Regional Research 16(4), 588–601 (1992)
9. Hernandez, D.: Uneven mobilities, uneven opportunities: Social distribution of public transport accessibility to jobs and education in montevideo. Journal of Transport Geography 67, 119 – 125 (2018)
10. Hernández, D., Hansz, M., Massobrio, R., Davyt, J.: Transporte público urbano y la accesibilidad a las oportunidades laborales. Disponible en línea: https://ucu.edu.uy/es/node/47195. [December 2019] (2019)
11. Hipogrosso, S., Nesmachnow, S.: Analysis of sustainable public transportation and mobility recommendations for montevideo and parque rodó neighborhood. Smart Cities 3(2), 479–510 (2020)
12. Hipogrosso, S., Nesmachnow, S.: Sustainable mobility in the public transportation of montevideo, uruguay. In: Smart Cities, pp. 93–108. Springer International Publishing (2020)
13. Huang, B., Chiou, S., Li, W.: Accessibility and street network characteristics of urban public facility spaces: Equity research on parks in fuzhou city based on GIS and space syntax model. Sustainability 12(9), 3618 (2020)
14. Ingram, D.: The concept of accessibility: A search for an operational form. Regional Studies 5(2), 101–107 (1971)
15. Krizek, K., Horning, J., El-Geneidy, A.: Perceptions of accessibility to neighbourhood retail and other public services. In: Accessibility Analysis and Transport Planning, pp. 96–117. Edward Elgar Publishing (2012)
16. Lei, T., Church, R.: Mapping transit-based access: Integrating gis, routes and schedules. Int. J. Geogr. Inf. Sci. 24(2), 283–304 (2010)
17. Massobrio, R., Nesmachnow, S.: Urban data analysis for the public transportation system of montevideo, uruguay. In: Smart Cities, pp. 199–214 (2020)
18. Nesmachnow, S., Baña, S., Massobrio, R.: A distributed platform for big data analysis in smart cities: combining intelligent transportation systems and socioeconomic data for montevideo, uruguay. EAI Endorsed Transactions on Smart Cities 2(5) (2017)
19. Salonen, M., Toivonen, T.: Modelling travel time in urban networks: comparable measures for private car and public transport. Journal of Transport Geography 31, 143–153 (2013)
20. World Business Council for Sustainable Development: Methodology and indicator calculation method for sustainable urban mobility. Tech. Rep. 978-2-940521-26-5 (2015)