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Dynamic accessibility by car to tertiary care emergency services in Cali, Colombia, in 2020: cross-sectional equity analyses using travel time big data from a Google API

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ABSTRACT

Objectives To test a new approach to characterise accessibility to tertiary care emergency health services in urban Cali and assess the links between accessibility and sociodemographic factors relevant to health equity.

Design The impact of traffic congestion on accessibility to tertiary care emergency departments was studied with an equity perspective, using a web-based digital platform that integrated publicly available digital data, including sociodemographic characteristics of the population and places of residence with travel times.

Setting and participants Cali, Colombia (population 2.258 million in 2020) using geographic and sociodemographic data. The study used predicted travel times downloaded for a week in July 2020 and a week in November 2020.

Primary and secondary outcomes The share of the population within a 15 min journey by car from the place of residence to the tertiary care emergency department with the shortest journey (ie, 15 min accessibility rate (15mAR)) at peak-traffic congestion hours. Sociodemographic characteristics were disaggregated for equity analyses. A time-series bivariate analysis explored accessibility rates versus housing stratification.

Results Traffic congestion sharply reduces accessibility to tertiary emergency care (eg, 15mAR was 36.8% during peak-traffic hours vs 84.4% during free-flow hours for the week of 6–12 July 2020). Traffic congestion sharply reduces accessibility to tertiary emergency care. The greatest impact fell on specific ethnic groups, people with less educational attainment and those living in low-income households or on the periphery of Cali (15mAR: 8.1% peak traffic vs 51% free-flow traffic). These populations face longer average travel times to health services than the average population.

Conclusions These findings suggest that health services and land use planning should prioritise travel times over travel distance and integrate them into urban planning. Existing technology and data can reveal inequities by integrating sociodemographic data with accurate travel times to health services estimates, providing the basis for valuable indicators.

STRENGTHS AND LIMITATIONS OF THIS STUDY

- ⇒ Our study investigated affordably measured dynamic accessibility to tertiary care emergency services for the entire population using massive amounts of measurements and provides an equity perspective.
- ⇒ The platform was developed using a person-centred design; it communicates findings using basic descriptive statistics, graphics and cartography.
- ⇒ Travel times account for traffic congestion and are a proxy for travel costs (ie, distance, cost and time).
- ⇒ Sources used to measure travel times are empirically known to be accurate, but variations of their precision across sectors and populations, like the algorithms behind the measurements, are unknown.
- ⇒ Models need to be retrained if conditions change ostensibly.

INTRODUCTION

Background and rationale

Every minute counts in life-threatening emergencies that do not leave time for referrals (eg, insufficient tissue oxygenation, critical bleeding, significant tissue damage and poisoning). The well-being of patients depends on getting immediate attention in a tertiary care facility that offers essential subspecialised care by highly skilled personnel and sophisticated facilities, including specialised surgical theatres and intensive care units.

This study tests a new approach that allows stakeholders to explore different assumptions and scenarios, for example, different time-to-destination thresholds, traffic congestion levels or accessibility for the whole or parts of the population.

The study delivers baselines for accessibility by car (automobile) to tertiary care emergency departments in Cali, Colombia. It assesses the impact of traffic congestion on accessibility and health equity, using a car (private or for hire) as the means of transportation because it is how Cali residents typically reach tertiary care facilities in emergencies. This approach also makes it possible for future studies to analyse accessibility with other means of transportation or under different assumptions.

Accessibility is a dynamic spatial attribute measured as the travel time needed to reach a health service location (destination) from the origin of the demand (place of residence in this study).[1–8] Travel times fluctuate over time and with traffic congestion. Accessibility has been challenging to study and monitor, and poor accessibility can be detrimental to health equity.[4 8–10]

Traditional assessments of accessibility in urban planning seldom consider its dynamic nature; origin–destination studies and surveys usually lack a dynamic assessment showing the effects of infrastructure, population changes or traffic on accessibility and health equity.[11 12]

Traditional assessments are onerous, done every 5–10 years, using lengthy surveys that lack the specificity of health services and the geographical granularity of traffic analysis zones or TAZs (instead of more expansive neighbourhoods or communes). The conditions assessed may have changed when results become public, rendering any proposed solutions irrelevant.[8 13] This study explores an approach that addresses critical limitations of traditional accessibility assessments to expose the links between equity and accessibility to tertiary care emergency services.[10]

Innovative approaches using accessible web-based platforms are an opportunity for evidence-informed decision making and planning to improve health coverage. These platforms allow stakeholders to test assumptions and reach conclusions and capitalise on features such as big data from smartphones that can provide accurate travel-time estimates. Therefore, dynamic, affordable and updatable assessments that account for traffic congestion could be used, thus focusing on travel times instead of travel distances.[5 8 12 14–17] They might allow stakeholders to explore data, test assumptions better and reach action-oriented conclusions.[18] This study integrates the equity-relevant data we used to perform equity analyses.

Objectives

This study aims to characterise accessibility to tertiary care emergency health services in urban Cali and the links between accessibility and sociodemographic factors relevant to health equity.

METHODS

Study population and setting

This study is about emergencies requiring attention in tertiary care institutions. By early July 2020, COVID-19 pandemic-related quarantine and stay-at-home orders had been lifted, and traffic projections showed substantial congestion. By November 2020, some measures had been reinstated, car travel was restricted by licence number and traffic projections showed reduced travel times, especially in central city areas.[19–21]

This cross-sectional study was conducted with data downloads for the urban area of Cali, the third largest city in Colombia and the largest urban centre in the southwest and Pacific regions, with an estimated 2.258 million residents in 2020. About half of the population lives in low-income housing, 42% in middle-income housing and 8% in high-income housing. Housing stratification does not necessarily represent the income of individuals.[22 23]

About 84% of the population identifies as white, 14% as Afro-Colombian and a small proportion as indigenous or nomadic people like the Rrom. In December 2020, unemployment rates in Cali were 26.7% for women and 18.5% for men, a 1-year increase of 12.5% and 8.8%, respectively.

The situation was worse among young people, and an estimated 52% of women and 47.2% of men relied on the informal economy. The COVID-19 pandemic punished the local economy. While one in five people was unemployed, the rates were higher among people in low-income households. Cali also absorbed 139 000 migrants from Venezuela between 2016 and 2020, including 25 000 in 2020.[24]

Poverty, inequity and discrimination drove social unrest that led to violence after a 2021 national strike.[25 26]

The city government is dividing its 22 communes into six to eight districts, which might lead to negotiations over resources and issues such as access to essential services.[27 28]

Targeted sites and participants

The study targeted the 14 tertiary care institutions with emergency departments registered in the Ministry of Health Special Registry of Health Services Providers (REPS in Spanish). The registry listed the same institutions in July 2020 and January 2021; all provided surgery and intensive care services. Those institutions are listed in online supplemental file 1.[29]

Study design

This study includes two cross-sectional analyses integrating publicly available data using digital technologies and analytics. The study generated new knowledge of potential value when implementing evidence-informed approaches to improve accessibility and health equity. The study used updatable data to measure travel times and evaluate the effects of interventions and changes to infrastructure, service provision, traffic congestion and population. The following study methods seek to address current challenges for assessments of accessibility to health services[10]:

- ► Dynamic assessments of travel times to account for traffic variations.
- ► Inputs from diverse stakeholders to create an interactive platform that displays intersectoral data on dashboards so stakeholders can interpret data quickly and accurately.

- Disaggregated data to enable straightforward equity analysis of accessibility.
- Situational analysis of the accessibility to specific services for urban areas.
- An approach suitable for monitoring health equity related to accessibility.

The data for the cross-sectional analyses were obtained from the internet-based AMORE Platform (https://www.iquartil.net/proyectoAMORE), hosted by iQuartil SAS, an analytics company, and developed under the leadership of the principal investigator (LGC).

The AMORE Platform integrates data from:

- 2018 National Census Data for Cali, obtained from the official public databases of the Colombian National Department of Statistics (DANE in Spanish).[22 23]
- The administrative divisions of Cali were obtained from the Colombian IDESC Geoportal; Traffic Analysis Zones (TAZ) were matched to the census blocks.[13 30] The origin for each journey is the population-weighted centroid for the TAZ of the place of residence. Similarly, the destination is the centroid for the TAZ hosting the tertiary care emergency department with the shortest travel time.
- Google Distance Matrix API. For this baseline assessment of the Cali urban area, predicted travel times were downloaded on 3 July 2020 for the week of 6–12 July 2020, and on 27 October 2020, for the week of 23–29 November 2020. Travel times varied substantially during the COVID-19 pandemic and while it is unclear how this influenced Google Distance Matrix algorithms,[31] empirical and anecdotal reports suggest they remained accurate.
- The 14 tertiary care institutions with an emergency department in Cali were identified using REPS.[29]

Databases were integrated and tested between August 2020 and October 2021 using: KNIME open-source data analytics reporting and integration platform, Python programming language software (back end) and an interface (front end) developed with interactive data visualisation software Microsoft PowerBi.

Patient and public involvement

The AMORE Project Collaborative Group is diverse, with over two dozen contributors representing different stakeholders and sectors. Group members participated throughout the design, conduct and reporting of this study and the dissemination of results. The contributors and some public servants participated in the cocreation of knowledge and are listed in the Acknowledgements. These collaborators offer different governance perspectives: authorities, service providers, service users and organised civil society, including academics, advocates and experts from various fields of knowledge.[32 33]

Data integration and output

The AMORE Platform dashboards and visualisations provide descriptive indicators using simple maps, dials, bars and data. These indicators show travel times using the shortest journeys and descriptive statistics for each urban TAZ at a given traffic congestion level. The displays for July and November can be accessed on the project's website. The AMORE Platform allows users to perform equity analyses by disaggregating sociodemographic characteristics.[34] The top section of the Platform (figure 1) has nine traffic congestion clusters and their representation in the week. A dial shows the share of the population within the set travel time threshold.

The middle section displays a population pyramid and maps the 14 tertiary care emergency departments, travel times and population density (figure 1). Each section of the pyramid or map can be toggled to filter populations. The choropleth maps can be expanded and rotated for a 3D display, with TAZ height representing population density (online supplemental file 2). Selecting a TAZ displays its ID, population and travel time.

Choropleth maps consist of TAZs established by MetroCali (Integrated Mass Transit System) in 2015 for the urban area and linked to the geotagged census block information, matching the population with these TAZs.[13] The geometric matching of blocks and TAZs yielded 507 inhabited TAZs within the urban perimeter.

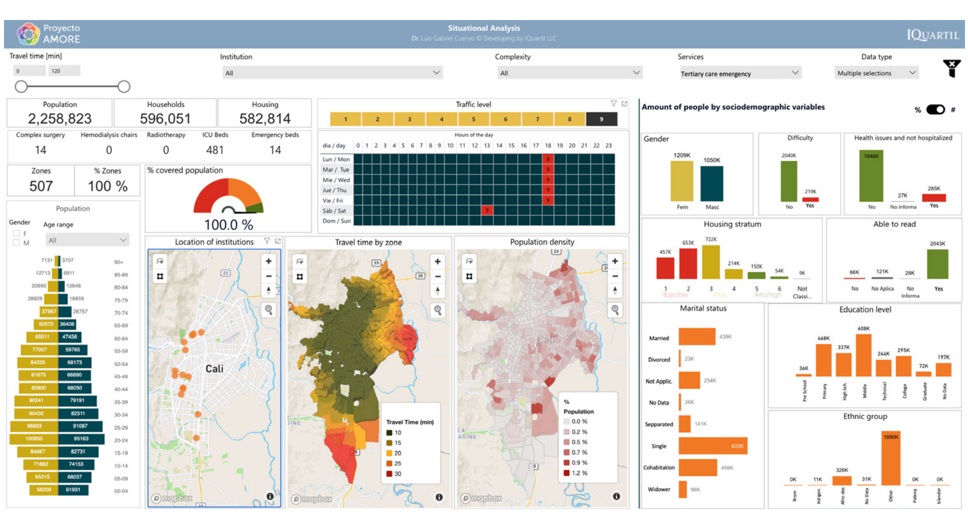

Figure 1 AMORE Platform situational analysis.

The origin–destination times were estimated from the population-adjusted geographic centroid of each TAZ to the respective centroid where each institution was located.

The Colombian census was completed through interviews with an adult for each household. Data were stored, linking it to a city block code to anonymise it. The AMORE Platform used the census microdata categorisations and, for a few variables, aggregate groups for simplification (eg, education was simplified with guidance from an expert in the Colombian education system, Psychologist Myriam Lorena Rosero Hernández, ME).

In 2019, Colombia's National Administrative Department of Statistics (DANE in Spanish) recommended adjusting the 2018 population of Cali upward by 18% from the original census data due to under-registration.[23 35] DANE advised making further adjustments due to intercensal growth, migration and updates.[24 36] These adjustments amounted to 28.1%, and DANE did not disaggregate the adjustment data. Therefore, 495 219 records were randomly selected and duplicated, reaching a population of 2 258 823 inhabitants, keeping the distributions. These are displayed in the AMORE Platform by toggling the census adjustment (figure 1, 'Data type').

The right section of the platform displays sociodemographic characteristics (figure 1).

The AMORE Platform displays the absolute and relative figures for the georeferenced data of inhabitants, both for the city or selected TAZs within a travel schedule figure 2. The variables integrated into the platform are listed in table 1.

Table 1 Census data included in the AMORE Platform dashboards and maps

Geotagged variables	Platform display
Age in completed years grouped by quinquennium (census)	Population density per TAZ
Ethnicity, self-described	Health service: tertiary care emergency departments
Health status (sick/healthy)	Absolute and relative figures of modified aggregation
Highest education level attained	Travel time thresholds (slider+choropleth heatmap)
Literacy	Travel times and population per TAZ
Marital status	Overall accessibility for filtered population
Population pyramid by gender and age	
Report of disability/physical condition	
School attendance	
Household inhabitants	
Housing inhabitants	
Housing socioeconomic stratum	
Housing type	

We used the controls listed in box 1 to conduct univariate and bivariate analyses.
TAZ, traffic analysis zone.

Data sources and measurements

Bias

Each source is susceptible to biases and imprecision, but these are unlikely to be of a magnitude that would change conclusions. Some of the data sources and the timing of their updates can introduce bias. For example, the census is updated every 5 years. Since the last census in 2018, there has been a significant flow of migrants to Cali, and job losses rose during the COVID-19 pandemic.[24 37] These developments likely make our

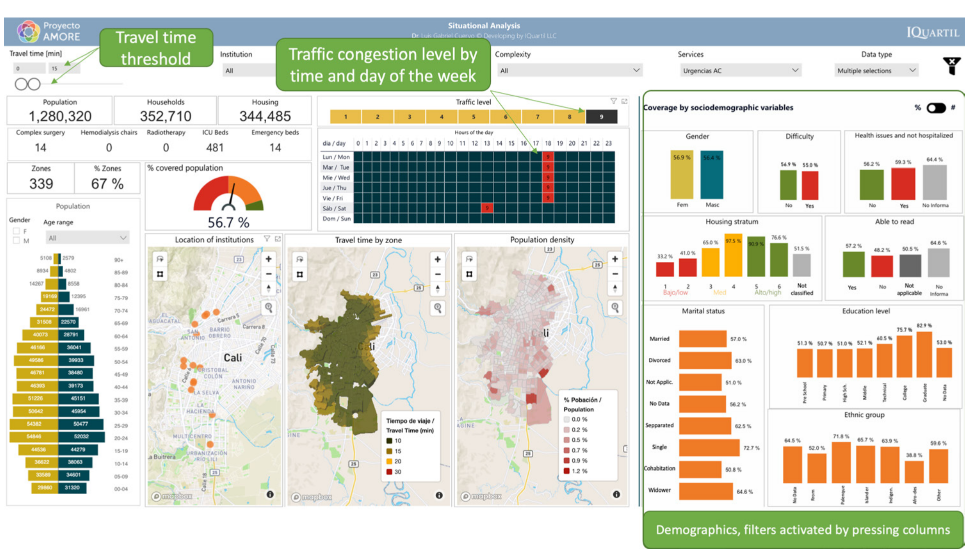

Figure 2 Situational analysis, filters and visualisations 21 November 2020.

Box 1 AMORE Platform displays resulting from integrating travel times with census data and the traffic analysis zone (TAZ) for the residence and destination health service

Variables that change according to traffic, travel time threshold and other filters.
Travel time threshold filter for the analysis.
Drop-down list with institutions that can be toggled for inactivation.
Drop-down list to select people registered by the census, the 28.1% adjustment or the adjusted census data.
Traffic levels identified with a K-means clustering algorithm.
Absolute and relative figures or each variable.
Choropleth maps organised by TAZs.
Intensive care beds data for selected institutions taken from the Special Registry of Health Services Providers (REPS).
People with accessibility for a selected time threshold and traffic level.
Blocks with accessibility for a selected time threshold.
TAZs within the time threshold by traffic level.
Household inhabitants.
Housing inhabitants.
Housing by power bill economic stratum.

results appear more favourable than they are. The census had under-registration from failed or incomplete visits, under-reporting of people living in households or people absent in each of the three times registrars visited. The estimates for migrants and intercensal growth are broad and likely unevenly distributed among the population, and no precise measurement errors are available.[23 24]

Traffic patterns may have changed with the imposition and lifting of pandemic-related restrictions, thus altering traffic predictions. Stay-at-home orders and traffic restrictions may have changed traffic congestion, causing unusual and uneven patterns of accessibility. Google Distance Matrix API may have more accurate travel times for areas where more people travel with mobile phones and in cars.

Income categorisation is determined by the individual household electricity bill, which is graded from 1 to 6, with 6 representing the highest income households. Some homes may have been misclassified (eg, due to error or corruption) and that low-income people are living in higher income households. This is possible for relatives and domestic workers residing in high-income housing and earning minimum wages or having no income. This kind of misclassification would introduce some bias that would over-represent high-income populations.

The Colombian census recognises ethnicity, but some people likely found it difficult to choose their ethnicity. The census lacks an option for residents of white or mestizo descent, two large groups not explicitly listed on the census. Similarly, people with multiethnic parents may find it challenging to choose one ethnic category.

Traffic restrictions linked to car licence numbers affect households and neighbourhoods differently; more affluent families are more likely to own more cars and be less affected by these measures.[38]

To reduce data downloads, we performed a cluster analysis (using a K-means method) of the travel times on a sample of the total weekly hours. This allowed us to identify the hours of the week with similar traffic congestion levels by measuring the incremental changes against the minimum travel time. We determined that nine clusters allowed us to discriminate traffic congestion based on sensitivity analysis to represent the 168 hours of the week.

For each day and hour time band, we estimated the percentage difference between the minimum time of that trip and the travel for the time band. We calculated the average of this metric for all the journeys of the sample to obtain clusters. For example, the traffic from 18:00 to 19:00 on weekdays and from 12:00 to 14:00 on Saturdays behaves similarly for this cluster, representing the highest traffic congestion. Creating these clusters again reduces information requirements and costs.

Using hourly assessments is arbitrary; travel times could be measured every minute or second. However, more frequent checks would increase costs (ie, from data downloads, computing time, people time) by orders of magnitude without substantive changes in the conclusions. More frequent checks would thus be impractical and of little value. Details of the effects of these optimisations will be the subject of a future manuscript.

Using congestion clusters and TAZs for the 14 institutions made it possible to obtain the city estimates with a sample of 1159536 measurements downloaded from Google Distance Matrix API. The geometric matching of blocks and TAZs yielded 507 inhabited TAZs in the urban perimeter.

Populations are not evenly distributed across TAZs. We therefore adjusted TAZ geographic centroids by weighing population distribution. Because centroids had irregular shapes, population-weighted centroids could end outside the boundaries of a TAZ. This required relocating the adjusted centroid to the nearest border, potentially generating some seconds of imprecision in estimates. Similarly, using the TAZ of a hospital instead of the location of the emergency department entrance also generates imprecisions.

Traffic patterns are not homogeneous within the city or its TAZs; traffic flow patterns vary in time and direction. We therefore sorted traffic times so that cluster 9 always represented the maximum traffic congestion, cluster 1 the minimum traffic congestion and intermediate clusters were sorted accordingly. Figure 3 illustrates the clusters and variations.

The definition of an acceptable travel time threshold to reach a tertiary care emergency department is arbitrary, and we found no international standard. For this analysis, we chose a threshold of 15 min at peak-traffic congestion times that was the most frequently considered by interviewed local public servants and members of the AMORE Project Collaborative Group; it is within the thresholds found in the literature.[39–41]

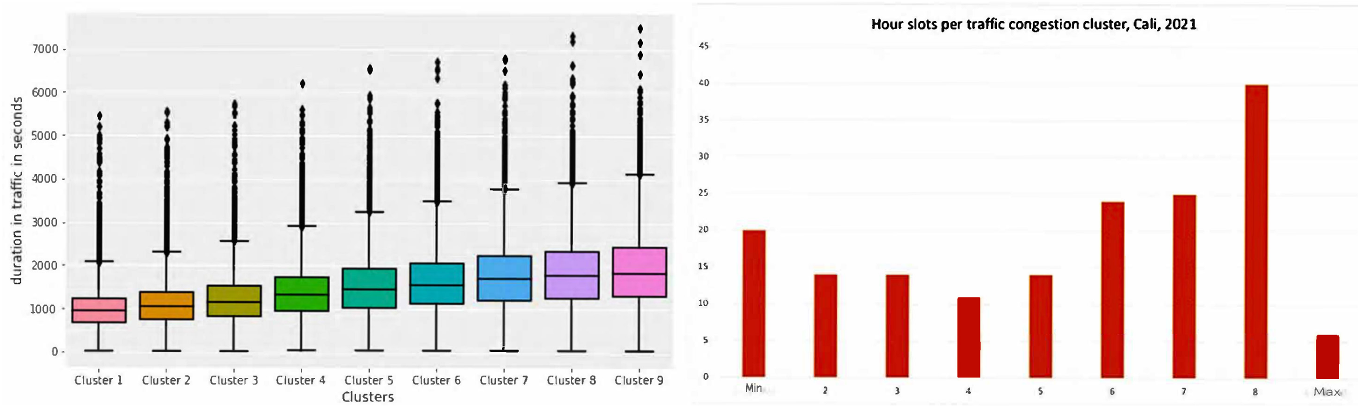

Figure 3 Travel time clusters from free-flow to peak traffic, by time and day.

Notably, the distribution of traffic levels is skewed towards heavy congestion from Monday to Saturday between 06:00 and 22:00, with the mode being cluster 8 (40/168 hours, or 24% of the week); Cali is a congested city.

RESULTS

Participants

The study included the adjusted population of 2 258 823 people, representing 596 051 households living in 582 814 housing units. The size and representation of populations are disaggregated in table 2.

Most of the population is mestizo or white (83.7 %) or Afro-descendants (14.5%). Islanders and Rrom people represent less than 1% of the population. Absolute and relative figures disaggregated by sociodemographic characteristics are presented in table 2.

Descriptive data

The analysis found that most of the low-income population could not reach the nearest tertiary care emergency department within 15 min during peak-traffic times, whether in July 2020 (92.3%) or November 2020 (81.4%; online supplemental file 2 and online supplemental file 3, respectively).

The analysis also shows that accessibility is a substantial barrier to low-income households with high population density and those living in peripheral TAZs, amplifying inequities.

Main results

The effects of traffic disaggregated by household income level, ethnicity, gender and age, education level, and civil status are presented in figures 4–6; table 2 shows differential accessibilities by housing stratum during peak and free-flow traffic hours, with the differential being more detrimental to the poorest and more affected by peak-traffic congestion.

Traffic variations and their effect

6–12 July versus 23–29 November 2020

The July travel time predictions pointed to 831 982 people (36.8%) living within 15 min of travel time from tertiary care emergency services, but this increased to 1.28 million (56.7%) in November. The distribution of accessibility when disaggregating data by income level indicated lower accessibility for the poor and those living in peripheral TAZs (figures 4 and 5, and evident in online supplemental file 2 and online supplemental file 3 to those familiar with the demographic distribution of Cali). These populations also have a higher representation of minority ethnic groups and people with lower educational attainment.

table 2 shows the data obtained from the AMORE Platform for the July 2020 and November 2020 assessments, which lets users explore equity considerations.

Other analyses

Figure 6 shows that people living in low-income households face longer travel times and are more severely impacted by traffic congestion; they thus invest more resources in accessing services.

Myriads of analyses can be done by modifying traffic congestion clusters, travel time thresholds or toggling population groups or institutions. For pragmatic reasons, this article focused on sticking to the 15 min threshold and exploring accessibility at peak hours in more detail, which is a good scenario when planning for emergencies.

Palenque, Islanders, Rrom and indigenous people represent 0.5% of the population of Cali. Minority ethnic groups benefitted the most from the reduction in traffic congestion. The noticeable improvement among the Palenque resulted from most living in the southeastern neighbourhoods of El Morichal, El Retiro, El Vallado and Ciudad Córdoba, which fell within the 15 min threshold when traffic eased in November (see figure 7).

DISCUSSION

Main findings

The analysis shows substantial variations in access to tertiary care emergency services due to traffic congestion and the links between geographical accessibility and other social determinants of health. The two points of estimate were for early July and late November 2020, and their substantial variations stress the importance of having updatable sources.

The unusually light traffic congestion of November 2020 might have been due to the mobility restrictions associated

Table 2 Accessibility by auto within 15 min to tertiary care in July and November, Cali 2020

15 min accessibility to the nearest tertiary care emergency service	July 2020 (%)	November 2020 (%)	Change (%)	July 2020 (#)	Nov 2020 (#)	Change (#)	Total population	%	Accessibility July (%)	Accessibility November (%)	Subgroup change (%)
	36.8	**56.7**	**19.8**	**831 982**	**1 280 320**	**448 338**	**2 258 823**		**36.8**	**56.7**	
Socioeconomic stratum											
Low	7.7	18.6	10.8	174 869	419 448	244 579	1 109 549	49.1	15.80	37.8	22.0
Middle	22.0	30.0	8.0	496 558	677 967	181 409	935 699	41.4	53.1	72.5	19.4
High	7.0	7.9	0.9	157 682	178 277	20 595	204 589	9.1	77.1	87.1	10.1
N.D.	0.1	0.2	0.1	2873	4628	1755	8986	0.4	32.0	51.5	19.5
Ethnicity											
Afro descendent	3.1	5.6	2.5	70 394	126 298	55 904	325 865	14.4	21.6	38.8	17.2
Rrom (nomadic)	0.0	0.0	0.0	37	53	16	102	0.0	36.3	52.0	15.7
Indigenous	0.2	0.3	0.2	3571	7103	3532	11 112	0.5	32.1	63.9	31.8
Islander/Raizal	0.0	0.0	0.0	182	251	69	382	0.0	47.6	65.7	18.1
Other (Caucasian, mestizo)	32.9	49.9	17.0	743 469	1 126 671	383 202	1 890 491	83.7	39.3	59.6	20.3
Palenque	0.0	0.0	0.0	29	176	147	245	0.0	11.8	71.8	60.0
N.D.	0.6	0.9	0.2	14 300	19 768	5468	30 626	1.4	46.7	64.5	17.9
Educational level											
Graduate degree	2.1	2.7	0.5	47 785	60 019	12 234	72 441	3.2	66.0	82.9	16.9
Bachelor's degree	7.4	9.9	2.5	166 816	223 602	56 786	295 319	13.1	56.5	75.7	19.2
Technical	4.3	6.5	2.2	97 733	147 634	49 901	244 160	10.8	40.0	60.5	20.4
Middle	8.7	14.0	5.3	196 674	316 810	120 136	608 429	26.9	32.3	52.1	19.7
High school	4.7	7.6	2.9	105 509	171 843	66 334	337 065	14.9	31.3	51.0	19.7
Primary	6.3	10.5	4.3	141 309	237 344	96 035	468 206	20.7	30.2	50.7	20.5
Preschool	0.5	0.8	0.3	11 158	18 636	7478	36 294	1.6	30.7	51.3	20.6
No data	2.9	4.6	1.7	64 998	104 432	39 434	196 909	8.7	33.0	53.0	20.0
Literacy											
Literate	33.8	51.7	17.9	764 426	1 168 883	404 457	2 043 041	90.4	37.4	57.2	19.8
No literacy	0.8	1.4	0.6	17 927	32 006	14 079	66 383	2.9	27.0	48.2	21.2
N.A.	1.6	2.7	1.1	36 401	61 180	24 779	121 140	5.4	30.0	50.5	20.5
N.D.	0.6	0.8	0.2	13 228	18 251	5023	28 259	1.3	46.8	64.6	17.8
Gender/sex											
Female	19.9	30.5	10.6	449 188	688 160	238 972	1 208 617	53.5	37.2	56.9	19.8
Male	16.9	26.2	9.3	382 794	592 160	209 366	1 050 206	46.5	36.4	56.4	19.9

Continued

Table 2 Continued

15 min accessibility to the nearest tertiary care emergency service	July 2020 (%)	November 2020 (%)	Change (%)	July 2020 (#)	Nov 2020 (#)	Change (#)	Total population	%	Accessibility July (%)	Accessibility November (%)	Subgroup change (%)
	36.8	**56.7**	**19.8**	**831 982**	**1 280 320**	**448 338**	**2 258 823**		**36.8**	**56.7**	
Civil status											
Single	13.4	20.7	7.3	303 645	468 447	164 802	821 536	36.4	37.0	57.0	20.1
Married or cohabitation	14.6	22.6	7.9	330 460	509 814	179 354	896 958	39.7	36.8	56.8	20.0
Divorced or separated	2.9	4.2	1.3	65 978	95 928	29 950	163 980	7.3	40.2	58.5	18.3
Widow	1.9	2.6	0.8	42 743	59 804	17 061	95 611	4.2	44.7	62.5	17.8
N.A.	3.4	5.7	2.3	76 821	129 370	52 549	254 492	11.3	30.2	50.8	20.6
N.D.	0.5	0.8	0.2	12 335	16 957	4622	26 246	1.2	47.0	64.6	17.6
Age											
0–4	1.6	50.5	48.9	36 401	61 180	24 779	121 140	5.4	30.0	50.5	20.5
0–14	5.4	50.9	45.6	121 111	204 055	82 944	400 527	17.7	30.2	50.9	20.7
5–14	3.8	51.1	47.4	84 710	142 875	58 165	279 387	12.4	30.3	51.1	20.8
15–24	5.3	53.9	48.6	120 001	195 693	75 692	363 311	16.1	33.0	53.9	20.8
15–59	23.8	56.4	32.7	536 754	836 078	299 324	1 482 069	65.6	36.2	56.4	20.2
15–64	25.9	56.7	30.8	585 558	904 942	319 384	1 595 016	70.6	36.7	56.7	20.0
60+	7.7	63.8	56.1	174 117	240 187	66 070	376 227	16.7	46.3	63.8	17.6
65+	5.5	65.1	59.5	125 313	171 323	46 010	263 280	11.7	47.6	65.1	17.5
80+	1.5	69.0	67.6	33 380	44 248	10 868	64 100	2.8	52.1	69.0	17.0
	36.8	56.7	19.8	831 982	1 280 320	448 338	2 258 823				

NA, not applicable; ND, no data .

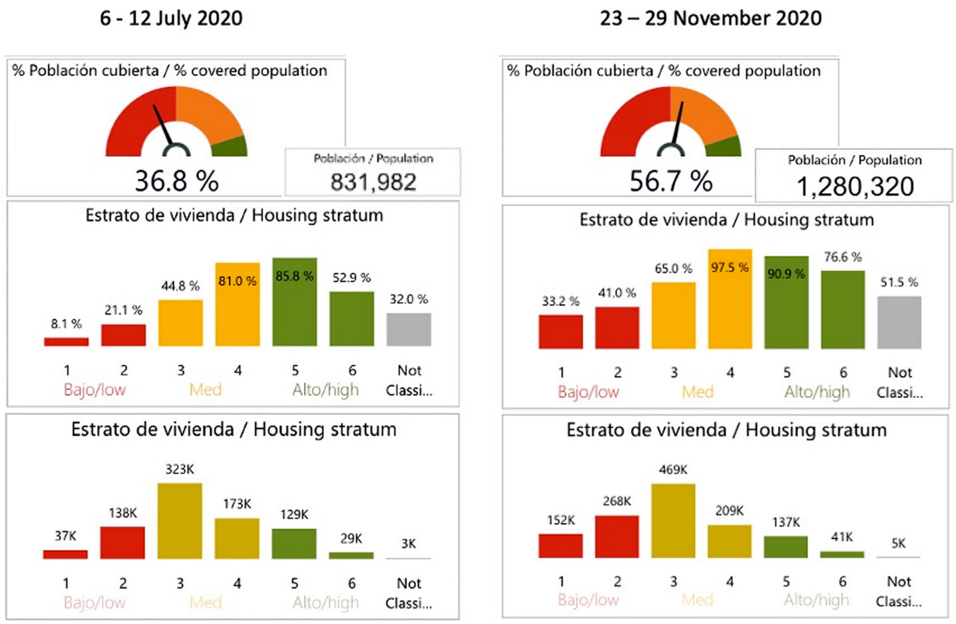

Figure 4 Accessibility by income to tertiary care comparing July and November 2020.

with the COVID-19 pandemic. Lighter traffic congestion improved accessibility for an additional 448 338 people, most living in low-income households. These people were also within the 15 min threshold (figure 4), and their location can be visualised by comparing online supplemental file 2 and online supplemental file 3. Table 2 shows accessibility at peak-traffic hours disaggregated by sociodemographic characteristics relevant to equity.[42–44]

The longest journeys were 46 min in July and November. These journeys started from densely populated, impoverished eastern neighbourhoods along the Cauca River (Aguablanca district) and sparsely populated wealthy villas in the southern edge of the city, bordering Jamundí.

Easing traffic congestion brought an additional 22% (244 579) of people in the low-income household and 19.4% (181 409) more people living in middle-income households within the 15 min threshold.

Improvements were not notably disparate among the different groups (sex, educational attainment and literacy, age and civil status). In terms of education, people with higher educational attainment (a bachelor's degree or higher) were less impacted by traffic changes (69 020 people) and those with lower educational attainment were more highly impacted (eg, 282 505 people with primary, middle, high or technical school education). The variations seemed unimpressive in relative terms but are notable in absolute numbers, considering that an

Figure 5 Accessibility by sociodemographic characteristics in July and November 2020.

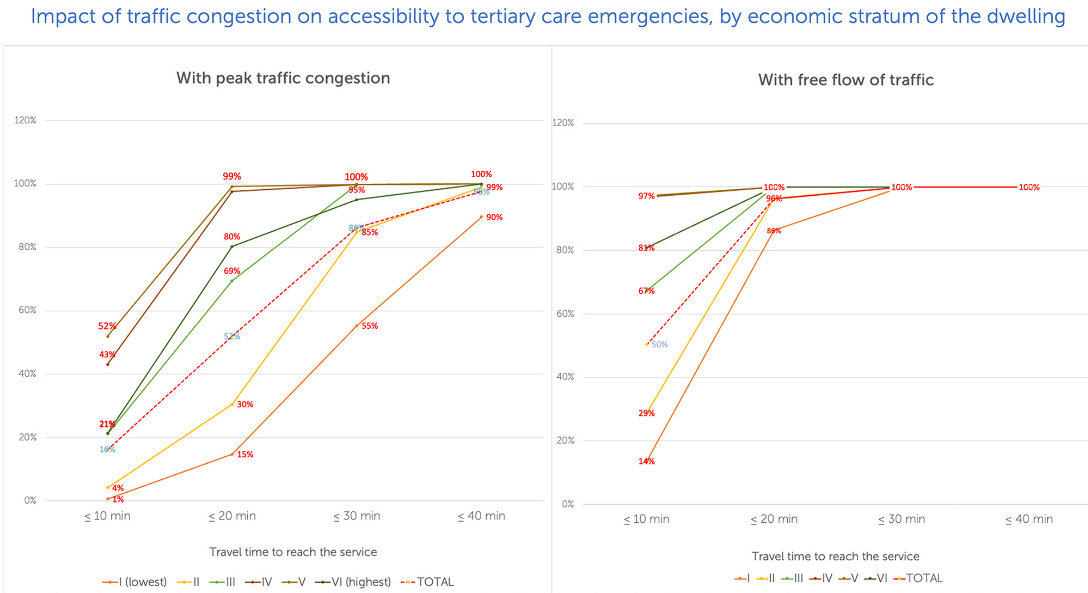

Figure 6 Impact of traffic congestion on accessibility, by economic stratum, July 2020.

Figure 7 Location of the Palenque people.

additional 332 406 people with primary, middle, high or technical school education were included as congestion eased. Variations in congestion resulted in substantial accessibility improvement, with nearly half a million more people within a 15 min accessibility threshold, almost 20% of the population.

Comparing age groups, children and the young and working age populations gained more accessibility with the changes in traffic, as the elderly tend to live closer to health services.

Variations in traffic congestion can lead to notable accessibility measurement changes among populations that concentrate around the borders of assessed travel time thresholds, as seen among the Palenque people.

Online supplemental files 2 and 3 show that tertiary care health services are far from where most of the population lives. Geospatial analysis, big data, and predictive and prescriptive analytics could inform service planning in ways that maximise accessibility if new services address these limitations.

Limitations

The AMORE Platform used data modelling and clustering to estimate travel times between the origin and destination TAZ, lowering the cost of using big data and still delivering accessibility. Operational costs are thus low, and platform updates for monitoring and evaluation are affordable. The trade-off for affordability is imprecisions in estimates. These imprecisions are more likely to affect populations living near the 15 min threshold and those further away from TAZ centroids with heavy traffic congestion. However, these imprecisions are unlikely to change the overall urban assessment.

Predicted travel times from the Google Distance Matrix API are accurate and are fed by big data from smartphones. Other databases, such as Waze Transport SDK API, can be used to generate estimates, but these providers do not release prediction algorithms. It is thus impossible to know the magnitude and variations introduced by unforeseen events, like pandemic-related restrictions, and to estimate the impact of resulting errors or biases on estimates.

Colombian law requires hospitals to treat patients in emergencies. Modelling for this study assumed that people would resort to the hospital with the shortest travel time. However, people may go to a different hospital if they know it better, their insurer recommends it or it has a good reputation. Our estimates are thus likely optimistic.

While choropleth maps allow users to explore the travel times from a specific TAZ, panels do not reflect that a origin of a journey will not always be the place of residence. This limitation will spread differently at different times and for diverse populations.

The relevance of our findings could change if the registered tertiary care facilities changed in REPS (ie, a new institution opens, or an existing institution is reclassified as tertiary, changing the results). The interactive platform allows for prompt updates and reanalysis in response to these contingencies.

Interpretation

The AMORE Platform reveals accessibility and its health equity implications, providing new dynamic data that account for the effects of traffic. It does so more precisely and at a fraction of the costs of household surveys and origin–destination studies, providing a new tool to inform service plans, programmes and policies.

Integrating publicly available data from public sources might be a breakthrough that improves evidence-informed decisions regarding the location and provision of health services. Visualisations might help stakeholders interpret the data and agree on a common objective and metric: painting the city green by covering its entire population and offering equitable accessibility to all people.

Updating the AMORE Platform is cheaper and faster than updating other origin–destination studies; its assessments are granular and sensitive to variations and can be used to monitor and evaluate changes. In emergencies such as earthquakes, a modified platform could provide a prompt situation analysis by feeding real-time data downloads rather than predictions.

These findings suggest that with congested traffic in peak hours, most Cali residents (63%) are beyond the 15 min travel time threshold by car to the nearest tertiary care emergency department. However, this figure fell to 43% when traffic congestion eased.

Reduced accessibility is unevenly distributed and reflects the inverse care law: people who live in low-income households or have less education face longer journeys to tertiary care emergency departments. Incidentally, heavy traffic also affects people on the periphery of Cali, including some high-income households, as congestion clogs roads they use to reach tertiary emergency care facilities.

Accessibility is one of many potential access barriers to health services and a critical one. Other factors that affect access to healthcare (eg, rights, quality or supplies) are meaningless if patients cannot reach tertiary emergency care in a crisis. Additional barriers to accessing health services (such as non-compliance with Colombian law, perceived or present quality issues, or institutional reputation) are beyond the scope of this study and merit consideration.

Researchers and planners can use data mining to optimise new tertiary care emergency services locations that maximise accessibility. Data mining could inform which existing institutions should be prioritised for an upgrade to improve accessibility or point at the optimal location for new ones, thus informing sound choices. These data are unique and provide an opportunity to enhance health services planning. Stakeholders and health equity advocates should encourage the integration of accessibility considerations in urban planning processes.

Planners and service providers wishing to combat social injustices must examine this new evidence that distance and congestion combine to exclude the most vulnerable and socioeconomically disadvantaged from critical health services. Planners and service providers must then consider bringing services closer to these populations. This new evidence and approach raise opportunities to address inequities, improve indicators and engage stakeholders in urban planning. Future studies will examine the impact of this approach. This evidence supports planning using travel time and monitoring accessibility and equity when assessing the quality of health services.[45–47]

This situational analysis is insufficient to drive change. Integrating evidence about accessibility and equity into stakeholder and intersectoral dialogues, decision-making processes and other strategies that seek the social appropriation of knowledge by stakeholders and sectors might be catalysts for implementation.[33,48]

This report is part of the broader AMORE Project. Future reports will explore the potential of optimising the location of up to two new emergency departments. Future studies will assess the use and appropriation of data, and the advocacy of stakeholders, including those in the AMORE Project Collaborative Group (table 3).[10,49]

Interactive platforms can help decision makers explore different assumptions and myriads of other results of combining different thresholds and traffic levels, allowing data to speak for itself.[18,50]

Looking ahead, identifying and proposing public policy plans and partnerships could improve health equity and bring hope to residents of Cali. These measures could also reduce social injustices, including the burden of the inverse care law that vulnerable populations pay more to access essential health services.[4,51,52]

Table 3 Contributions by members of the AMORE Project Collaborative Group approving the manuscript

Surname	Given name	Draft writing	Revision and comments	Conceptual contributions	User perspectives	Stands by manuscript	Approved final version
Agredo Lemos	Freddy Enrique		•	•	•	•	•
Avila Rodriguez	German				•	•	•
Bula	María Olga	•	•	•	•	•	•
Concha Eastman	Alberto			•	•	•	•
Cuervo	Daniel	•	•	•		•	•
Cuervo	Luis Gabriel	•	•	•		•	•
Franco	Oscar			•		•	•
Garcia	Crhistian			•	•	•	•
Guerrero	Rodrigo		•	•	•	•	•
Hatcher-Roberts	Janet	•	•	•		•	•
Jaramillo	Ciro	•	•	•	•	•	•
Martínez Arámbula	Fernando Rafael			•		•	•
Martínez Herrera	Eliana	•	•	•	•	•	•
Merino Juárez	Maria Fernanda		•	•		•	•
Osorio	Lyda	•	•	•	•	•	•
Ospina	Maria B			•	•	•	•
Paredes	Gabriel		•	•		•	•
Paredes-Zapata	David		•	•	•	•	•
Pinilla	Luis Fernando	•	•	•	•	•	•
Piquero	Felipe	•	•		•	•	•
Rojas	Oscar		•		•	•	•
Rosero Hernández	Myriam			•		•	•
Tobar-Blandón	María Fernanda		•		•	•	•
Zapata Murillo	Pablo			•		•	•

Generalisability and applicability

This study is reproducible in other settings with dynamic travel time data (eg, Waze or Google Maps) and georeferenced service and population data that make situational analyses accessible. Information accuracy depends on the accuracy of sources, the modelling used to conduct searches and maintaining data that are affordable and easy to interpret.

Travel times, infrastructure and populations change. Travel times and census data may thus need to be updated, and traffic clusters may need to be adjusted.

The proposed approach highlights the dynamic nature of travel times and uses TAZs to offer a granular assessment of the city. The scale of these assessments is suitable for informing short-term or long-term policies and plans and can be periodically revised as conditions change.

Conclusions and future directions

These results test an approach to provide a situational analysis. Defining potential improvements by adding services and using data by decision makers and other stakeholders are part of the broader AMORE Project and the subject of future reports. Travel time is a continuous variable and could be the subject of myriad analyses beyond the purpose of this study. Our aim is to demonstrate the possibility of conducting an affordable situational analysis with existing data providing information that decision makers and other stakeholders might use, something to be assessed in future studies.

The web-based platform allows users to change assumptions or variables, explore different scenarios or perform sensitivity analyses. The possibilities are numerous and include expanding the study with more bivariate and multivariate analyses that go beyond the objectives of this report.

Ethical considerations

This observational study on quality improvement for health services planning does not research human subjects. It integrates anonymised coded secondary data sources obtained from publicly available open records.[53 54] No identifiable private information was used in the study. Oversight of the project has been provided by the Doctoral Programme on Methodology of Biomedical Research and Public Health at the Department of Paediatrics, Obstetrics & Gynaecology and Preventative Medicine at the Universitat Autònoma de Barcelona. Contributors to this study are members of the AMORE Project Collaborative Group and public servants in their official capacity; they are listed in the acknowledgements (table 3).

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Patient and public involvement Patients and/or the public were involved in the design, or conduct, or reporting, or dissemination plans of this research. Refer to the Methods section for further details.

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