Accessibility Analysis for Greater Cairo – The Role of Informal Transport

PART 1

1. Introduction

With a 2018 population of 20 million, the Greater Cairo Metropolitan Area (GCMA) is the 6th largest urban agglomerations in the world (UN-DESA 2018). It has been labeled as a 'primate city' due to the concentration of people and employment opportunities in it; over 20% of the country's population and 40% of jobs are in the capital (Sims 2010). The dominance of Cairo has been attributed to its historical significance (ibid) and to rural-urban labor migration at different periods in the 20th century (Zohry 2002; Davis 2004).

One major effect of this population concentration is severe congestion. A study commissioned by the World Bank estimated the total direct and indirect costs of congestion to be almost 50 billion EGP/year, with the cost per capita calculated as 15% of the GDP per capita (2013).

As congestion in Greater Cairo Region continues to get worse, the need for reforming the public transport network is becoming more urgent. One controversial mode of transport is the microbus (or shared taxi); this study attempts to provide insight on the importance of the microbus as a means of public transportation.

2. Literature Review

2.1 Commuting in the Greater Cairo Region (GCR)

As the city has grown, the public transportation system has failed to keep up with the demand for mobility. Private vehicles have proliferated; an analysis of the major corridors in the GCR found that 70% of vehicles were private cars ("Cairo Traffic Congestion Study - Phase 2" 2013), whereas public transport modes combined only accounted for 12% of vehicles. On a trip level, the numbers tell a different story. A 2001 study found that 68% of motorized trips in the capital were public transport trips and forecasted daily public transport trips to reach 20 million by 2022 ("CREATS" 2003)[1]. So, while private cars take up most of the road space, they only transport a small segment of the population.

This is not uncommon, and the purpose of this paper is not to make an argument against private vehicles, but to *focus on microbuses (or shared taxis) and their contribution to accessibility in the GCR*. A first step in doing so is understanding the different modes of public transport operating in the city. These modes can be categorized as formal or informal

[1] The 2003 Cairo Regional Area Transportation Study (CREATS) is the most recent report containing % of motorized-trips by mode

Formal Public Transport

The Cairo Transportation Authority operates a fleet of 40-seater buses and also gives out concessions to minibus operators. Official 2016 data shows that in 2016 there were around 420 bus routes and 51 minibus routes in operation (ACE Consulting Engineers and COWI 2016). The city is also served by three metro lines which are operated by the Egyptian Company for Metro Operation and Maintenance (ECM). These lines mainly serve central Cairo.

Informal Public Transport

The microbus, or 'shared taxi' is the primary mode of informal transport. Microbus licenses are given by the governorate in which they operate. Microbuses dominate the roads of Cairo; In 2001, 52% of public transport trips were done using microbuses, which was more than formal buses (28%) and the metro (17%) combined ("CREATS" 2003). Microbuses, while ubiquitous on the streets of Cairo, are also polarizing. They are criticized for their lack of organization, practice of stopping anywhere along the road, and for directly competing with the formal Cairo Transport Authority buses ("Sustainable Transport PIMS 3523" 2008). They are also considered to be an informal mode of public transportation given that there are only 20,000 licensed vehicles but over 100,000 actual vehicles operating in the city ("Greater Cairo: A Proposed Urban Transport Strategy" 2006).

However, they would not be so popular if they were not filling a demand gap. Along with private vehicles, they have filled the gap created by an inadequate formal public transport network ("Sustainable Transport PIMS 3523" 2008). They are able to extend beyond the reach of formal public buses, as their size makes them able to access the narrow roads of informal areas (Sims 2010). In 2009, over 60% of Cairo's population were living in informal settlements (Howeidy, Shehayeb, and Göll 2009).

At present, there is no functioning regulatory authority that oversees all public transport in the GCR (Klopp, Hegazy, and Kalila 2019)[2]. The result is an inefficient transport network with high competition between formal and informal transport modes. While the proliferation of informal transport can be said to be characteristic of developing countries, it is important to move beyond "the common academic imperative of linking an analysis of Cairo to global trends" (Sims 2010).

An analysis of how informal transport contributes to the accessibility of different areas of the capital is necessary to provide insight on the importance of integrating formal and informal public transport.

[2] The authors note the existence of the Greater Cairo Transport Regulatory Authority (GCTRA), but explain that it has no funding to operate

2.2 Why Use Accessibility As A Measure?

Accessibility is defined in this context as "the ease with which activities may be reached from a given location using a particular transportation system" (Morris, Dumble, and Wigan 1979).

Accessibility is considered essential to the economic prosperity of cities. Alain Bertaud theorized that the efficiency of cities depends on the extent to which the labor market is fragmented; the high operating costs in large cities is justified by the increased efficiency of a unified labor market (Bertaud 2004). This built on the work of Sveikauskas (1975) on increased productivity in large urban areas by showing that this increase is *conditional on access to the labor market*. Better access improves economic interactions between firms and increases competition by reducing distance barriers, allowing a wider talent pool into the labor market (Venables, Laird, and Overman 2014).

On the individual level, poor accessibility has been theorized to restrict life paths (Hägerstrand 1970), and to limit employment opportunities by limiting the potential for networking capital (Urry 2012). Higher accessibility has been directly associated with social inclusion (Stanley and Vella-Brodrick 2009) and improved psychological wellbeing (Delbosc 2012).

Better accessibility is also correlated with an increase in public transport mode share (Cui and El-Geneidy 2019). This means that focusing on improving public transport can be the solution to the congestion in the GCR. Given that traffic volumes on most of the road network is above the road capacities and forecasted to increase ("Cairo Traffic Congestion Study - Phase 2" 2013), an informed understanding of how the different public transport modes contribute to accessibility is necessary.

2.3 Accessibility Measures in Transport Analysis

There are various accessibility measures that are suited to different purposes. Measures of accessibility that are useful on an operational level are those that are able to compare the number of opportunities within a certain cost threshold of different residential locations (Wachs and Kumagai 1973). Integral measures are well suited for this purpose and so are popular in transport analysis (Makrí and Folkesson 2000). Two particular integral measures were considered for this analysis: Gravity Measures and Cumulative Opportunity Measures.

Gravity measures are based on the work of Hansen (1959). A gravity measure calculates a total accessibility score for each origin zone by weighing the opportunities at each destination by an impedance function that accounts for the cost of travel to that destination (as measured by distance or time). The impedance usually takes the form of an inverse power or a negative exponential.

Cumulative opportunity measures (Wachs and Kumagai 1973) calculate the number of opportunities within a specified distance or time threshold. All measures within the specified threshold are weighted equally. Prud'homme and Lee (1999) showed that this measure could be used to capture the effective size of any labor market, and Bertaud (2014) built on this by proposing that the labor market size can be estimated using a time threshold of 60 minutes.

3. Methodology

3.1 Chosen Measure for Accessibility

The chosen measure for accessibility is the cumulative opportunities measure. It is chosen for the following reasons:

1. The only accessibility analysis conducted for the GCR uses this method (Hegazy et al. 2019). This research aims to build on previous work.
2. Cumulative measures are clear and easy to communicate (Koenig 1980; Handy and Neimeier 1997). Ease of understanding is an important aspect of any policy-driven research.
3. It is grounded in the work of Bertaud (2014) on the effective size of labor markets
4. Unlike gravity measures, it does not require calibration of a decay parameter. Calibration is usually based on commuting flow data and such is not publicly available
5. It is less computationally expensive than a gravity measure; if a study area is divided into n plots, a cumulative measure would require n calculations whereas a gravity measure would require n^2 calculations.

3.2 Study Area

The analysis uses the boundaries of the GCR as defined by Hegazy et al. (2019). This is the 2013 urban agglomeration ("Atlas of Urban Expansion - Cairo" 2013) in addition to the new desert towns on the periphery. The study area is split up into 3 subdivisions[3]:

1. *Central Cairo*: Area within confines of the Cairo ring road
2. *Inner Cairo*: Area outside the Cairo ring road
3. *Outer Cairo*: New Desert Towns that have recently been built on the outskirts of Cairo (Sims 2015)

Figure 1: Outline of regions in study area

Table 1: Regional Population and Employment Statistics

	Area (km2)	Population (2018)	Workplace Jobs (2018)
Central Cairo	526.3	11,977,764	4,151,251
Inner Cairo	585.0	7,071,077	1,071,607
Outer Cairo	666.7	940,425	631,403

[3] The data is provided as a shapefile by Transport for Cairo, with population and employment figures included. The population figures are based on the 2018 census data and the employment figures are based on data from the Central Agency for Public Statistics and Mobilization (CAPMAS) and the Labor Force Survey

The Central Area can be considered mostly formal housing whereas the inner area is mostly informal housing on agricultural land. The ring road was built in the 1980's to limit the growth of the city and beyond it is informal housing built on agricultural land (El Batran and Arandel 1998). Although formality in Cairo does not adhere exactly to these strict boundaries, no detailed land-use classification could be found and so the above was used.

3.3 Accessibility Calculation

Local Accessibility Scores

The GCR is divided into equally sized areas (hexagons), and the accessibility for each origin area i is calculated by summing up the job opportunities available at all destination areas j (as a percentage of the total job opportunities in the GCR) that are within a 60 minutes commute by public transport.

$$A_i = \sum_{j=1}^{n} \frac{O_j * w_{ij}}{O_{tot}} \qquad w_{ij} \begin{cases} 1 \ (for\ t_{ij} \leq t_{max}) \\ 0 \ (for\ t_{ij} > t_{max}) \end{cases}$$

A_i : *the accessibility score of area i*
O_j : *the number of opportunities in destination area j*
O_{tot} : *the total number of opportunities in the GCR*
w_{ij} : *binary variable. depends on the travel time using public transit between i and j*
t_{ij} : *travel time between i and j*
t_{max} : *cutoff travel time* (60 min)
n : *total number of areas*

The chosen cutoff travel time (t_{max}) of 60 minutes is in line with Bertaud's definition of the size of a labor market being equivalent to the jobs reachable in less than an hour's commute (2014). The analysis uses a 2019 GTFS feed for Cairo (Hegazy and Melegy 2019) and OpenStreetMap (OSM) road data to query Open Trip Planner through the OpenTripPlanner R package (Morgan et al. 2019). This is done for the peak morning period only.

Regional and Metropolitan Wide Accessibility Scores

The accessibility score for each region is calculated by weighing each hexagon by its population and dividing by the total population of that region. A metropolitan wide score is calculated using the same logic

$$A_r = \sum_{i=1}^{m} \frac{A_i * P_i}{P_r}$$

A_r : *accessibility score of region r*
A_i : *the accessibility score of area i in region r*
P_i : *Population of area i*
P_r : *Total Population of region r* : $\sum_{i=1}^{m} P_i$
m : *number of areas in region r*

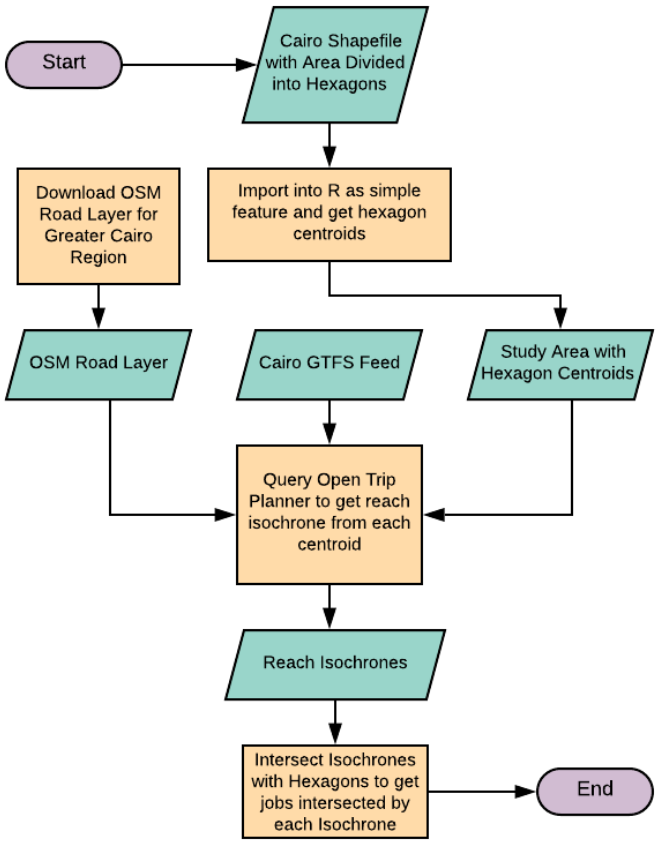

Figure 2: Getting Job Reach for Each Hexagon

PART 2

4. Results

The analysis shows accessibility to be low throughout the GCR. The highest job reach is around 2.1 million jobs when using all modes and 1.8 million jobs when only using formal modes. These translate to accessibility scores of 37% and 31% respectively. The highest job reach occurs in Central Cairo for both modes, with high accessibility in the areas around the metro lines. Accessibility decreases with increasing distance from the central area.

Accessibility levels are higher in Central Cairo. The accessibility levels for all areas increases when informal modes are added to the analysis. These increases are small but significant when considered relative to the low original accessibility scores. At 4.7%, the accessibility score for the whole GCR is much lower than the score of 24.5% reported by Hegazy et al. (2019).

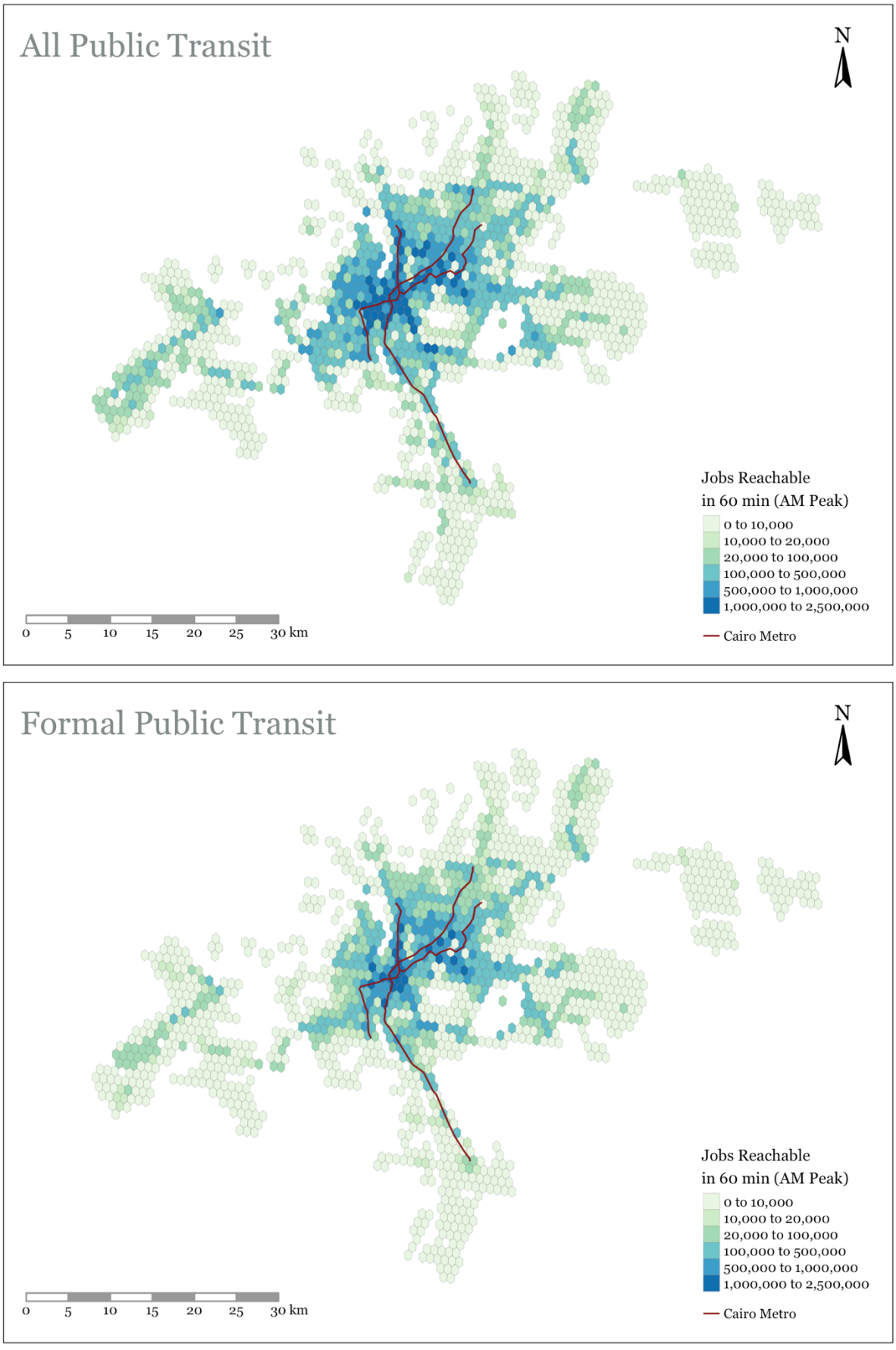

Figure 3: Jobs reachable using all modes of PT (Top) & jobs reachable using formal modes of PT (bottom)

Table 2: Regional + Metropolitan Level Accessibility Scores with and without informal Public Transport (PT)

	Average Job Reach		Accessibility Score			
	Formal PT	**All PT**	**Formal PT**	**All PT**	**Absolute Increase (%)**	**Relative Increase (%)**
Central Cairo	252,575	395,338	4.3	6.8	2.4	56.5
Inner Cairo	45,873	108,094	0.8	1.8	1.1	135.6
Outer Cairo	22,058	46,140	0.4	0.8	0.4	109.2
All GCR	***168,610***	***277,299***	***2.9***	***4.7***	***1.8***	***62.1***

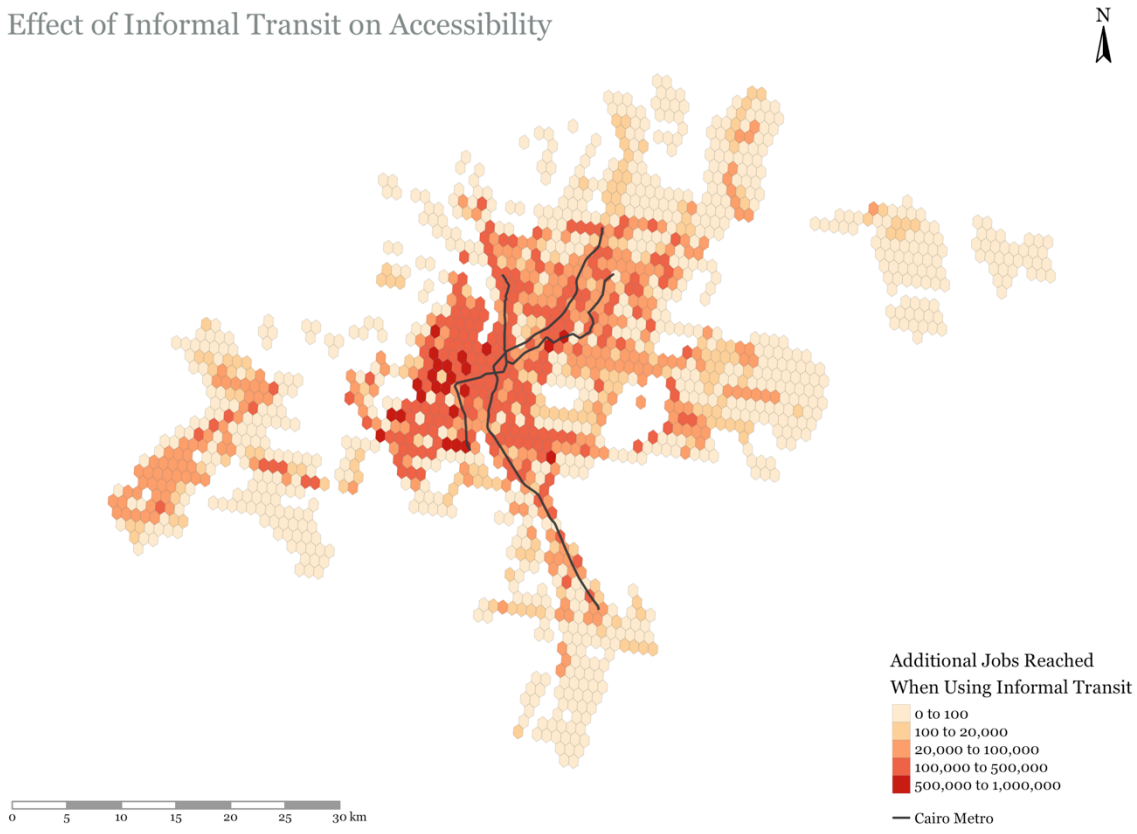

Figure 4: Effect of Informal Transport on Job Reach

Adding informal transport to the analysis is shown to increase the job reach in the central area more than the inner and outer areas. This is expected as job density is disproportionately higher in the central area, so the same reach polygon intersects with more jobs in the center.

5. Discussion

5.1 Accessibility Scores

The average accessibility score of 4.7% for the Greater Cairo Region is low. By comparison, the Greater London Authority has an accessibility score of around 44% (Smith 2018). Prud'homme and Lee (1999) explain that the accessibility score is positively affected by higher commuting speed, and negatively affected by urban sprawl. Given that the majority of the population and jobs are in central Cairo, sprawl only has a small effect. The low accessibility scores are indicative of an inefficient transport system and high levels of congestion. A closer look at the headways reveals that the transport network is not reliable.

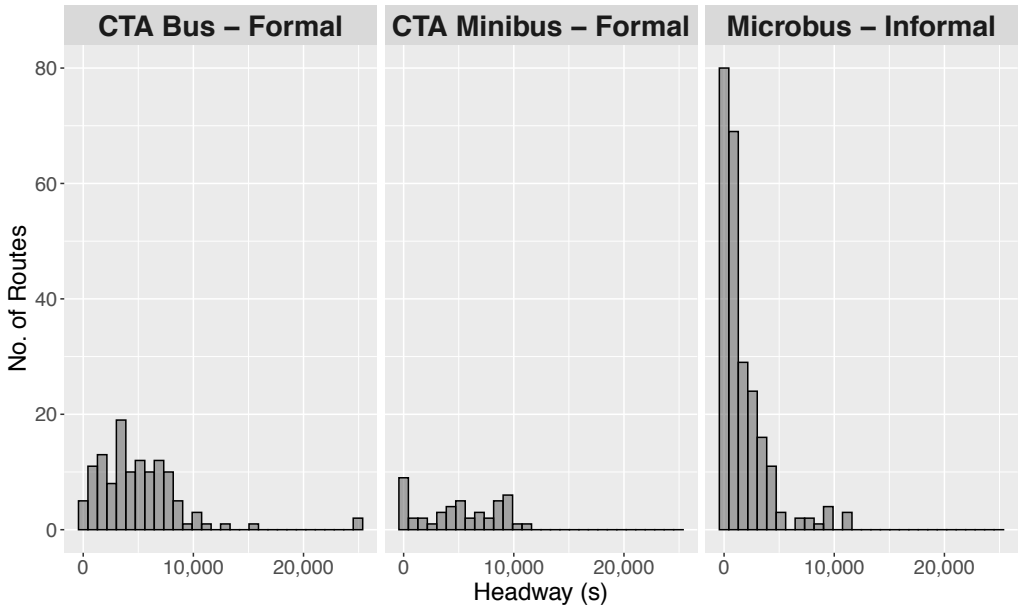

Figure 5: Headway distribution for PT routes, grouped by mode of public transport

Table 3: Mean Headway of PT modes

Agency	Mean Headway (minutes)
CTA Bus	82.7
CTA Minibus	84.3
Microbus	28.3

The average headway for formal buses is over 80 minutes, meaning that average waiting times on formal bus routes are around 40 minutes. Microbuses fare better with an average headway of 30 minutes. This shows that the CTA does not have enough buses to operate all its routes at an acceptable headway. A 2016 study confirms that over 80% of CTA buses operate with a headway over 30 minutes (ACE Consulting Engineers and COWI 2016). The same study explains that route allocation by the CTA is not evidence-based and neither routes nor headways are planned to match supply with demand.

The accessibility scores are highest in the central region. This is to be expected as most jobs are concentrated in that region and the metro predominantly serves the center. The accessibility for the outer region is the lowest. The low scores are the result of a combination of a) the shortage of jobs in the outer region and b) the commuting time to the central region (where most jobs exist). The new towns in the outer region are the most affected by the concentration of employment in the center; they have only 10% of the total jobs, even though they occupy a land area that is larger than both inner and central Cairo. Previous studies have argued that the travel distances from them to central Cairo are too long and a commute of over one hour is to be expected (Hegazy et al. 2019). For these towns, significant accessibility improvements may only come with rail infrastructure or local job creation. This points to the need for

'decentralized concentration' (Curtis 2008) whereby improvements in the transport network are done in parallel with local employment generation. Bertaud (2014) explains how a shift towards a composite city model, through the distribution of jobs, improves accessibility in outer areas of a city by reducing travel demand towards the central area and thereby alleviating congestion.

5.2 Role of Informal Transport

The addition of informal transport is shown to increase accessibility scores (Figure 4). In terms of jobs reached, the central area shows the highest improvement with an average gain of 140,000 additional jobs reachable. The central and inner areas show lower numbers of additional jobs reachable, but this should not be interpreted as the result of informal transport providing better service in the central area. The inner and outer areas experience a larger accessibility increase relative to their original scores, even though they show a lower absolute increase. The low scores show a need for integration between formal and informal modes of transport. A regulatory authority in charge of all public transport in the GCR would help allocate routes effectively and eliminate route redundancy, thereby improving accessibility.

5.3 Limitations

Integral accessibility measures capture the combined effect of land use and the transport network, but they cannot directly assess each component individually. If jobs were equally distributed across the study area, then the effectiveness of informal transport in different parts of the GCR could be interpreted directly from the variation in additional jobs reached.

In addition, the accessibility measure used focuses on only two components of accessibility; transport and land-use. The temporal and individual components are missing. The variation in accessibility throughout the day could have been analyzed, but it is unclear how much this will add given that the low peak-hour accessibility scores reveal a system in need of significant improvements. The individual component could have been taken into account, as studies have shown that 'occupational matching' affects the results of accessibility measures (Geurs and van Wee 2004). Bertaud (2014) argues that this is not a big limitation of the cumulative accessibility measure, as current labor markets are characterized by a proximity of people from different specializations; an increase in jobs reachable is correlated with an increase in specializations within the accessible region.

6. Conclusion

The study set out to measure accessibility by different modes of public transport across the GCR. It attempts to determine the importance of microbuses to the network by calculating where and by how much they effect accessibility.

The accessibility analysis shows the different levels of access and highlights where investment needs to be made. This analysis show that accessibility is low as you move away from the central region, highlighting the necessity for better transport links to the outskirts of the GCR. Informal transport is also shown to contribute to contribute significantly to accessibility.

The results show a need for reforming the public transport network in the GCR. Further research could be done to highlight where formal and informal transport modes are in direct competition. Removing redundant routes and reallocating buses to existing routes could be a low-cost measure to improve accessibility by improving bus headways. Such reallocation could be informed by modelling the accessibility changes resulting from headway improvement on specific routes.

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8. Appendix

Repository with Data and Scripts: https://github.com/Hussein-Mahfouz/GIS-Coursework

RPubs Website: http://rpubs.com/Hussein-Mahfouz/Accessibility-Analysis-Cairo