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مواصلة للقاهرة

Multimodal network planning, identification of high capacity bus corridor and park and ride facilities

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Title Picture: Bicycle Lane in El-Sheikh Zayed City. A dedicated bus lane and a cyclist are superimposed. Informal Transport is using the dedicated bus lane. (Collage by Transport for Cairo)

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List of Acronyms

Acronym	Description
5M	15 May City
6O	6th of October City
AFD	Agence Française de Développement
API	Application Programming Interfaces
AR	10th Ramadan City
BRT	Bus Rapid Transit
CREATS	Cairo Regional Area Transportation Study
CTA	Cairo Transportation Authority
EMOC	Egyptian Metro Operating Company
EIB	European Investment Bank
GCR	Greater Cairo Region
GIS	Geographic Information System
GTFS	General Transit Feed Specification
HSR	High Speed Rail
ITDP	Institute for Transportation and Development Policy
ITDP	Institute for Transportation and Development Policy
JICA	Japanese International Cooperation Agency
LFS	Labor Force Survey
LLP	Limited Liability Partnership
LRT	Light Rail Train
MoT	Ministry of Transport
NAT	National Authority of Tunnels
NC	New Cairo
NMT	Non Motorized Transport
NTRA	National Telecommunications Regulatory Authority
NUC	New Urban Community
OB	El-Obour
OD	Origin-Destination
OSM	OpenStreetMap
P+R	Park and Ride
PPTI	Potential Public Transport Infrastructure / Intervention
SQ	Shorouk
SZ	El Sheikh Zayed City
TfC	Transport for Cairo

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1.1. Introduction

1.1. Purpose of This Study

The lives and experiences of people are at the heart of urban life - and of this study - which assesses the multimodal travel options available to citizens at present, and in the future, to identify the optimal locations of future high capacity transit corridors and park and ride facilities.

As part of the preparatory work for a potential World Bank financed intervention into the Urban Mobility sector, Transport for Cairo was assigned to provide analysis and expert advice in the field of multimodal network planning in the Greater Cairo Region at the metropolitan scale.

The main expected outcomes of this assignment are the following:

I. to identify **3 key demand corridors** (for buses and/or BRTs) linking the New Urban Communities to Central Cairo
II. to identify **10 potential park-and-ride** sites in the New Urban Communities
III. to propose recommendations to enhance urban mobility and usability of the 3 recommended corridors:
   A. to draft principles to approach **integration of the existing informal transit with the planned formal system** along the recommended corridors for enhanced efficiency in the public transport system, contributing to a better user experience
   B. to propose strategic recommendations to **promote walking** around and access to the future public transport system stations of the recommended corridors
   C. to propose entry points to investigate the possibilities and benefits of having a **bicycle network** as a complementary feeder mode that enhances last mile connectivity along the recommended corridors and at endpoints located in the NUCs.

1.2. Scope of the Study

1.2.1. Geographical boundary of corridors and park and ride facilities identification:

The study area is limited to the Greater Cairo Region (GCR) administrative boundaries. These include the governorates of Cairo, Giza and Qalyubia. Within these administrative boundaries there are eight New Urban Communities (NUCs): 10th of Ramadan, 15th of May City, 6th of October, Badr City, El Sheikh Zayed City, El Shorouk, New Cairo and Obour City.

The scope of analysis, and thus of the recommendations, is limited to 'Inner' and 'Outer' zones[1] of the GCR, as defined within Figure 1. To achieve these recommendations, transport links within the 'Inner-Outer' zones and then 'Central' zones will be examined at the metropolitan scale (1:50000). Within the 'Inner' and 'Outer' zones, transport links, road & pedestrian networks, and other forms of data will be examined at the urban planning / city scale. (1:5000)

[1] 'Outer' zone areas are primarily delineated by the presence of a desert breaking continuous urban development between them and 'Inner' zones.

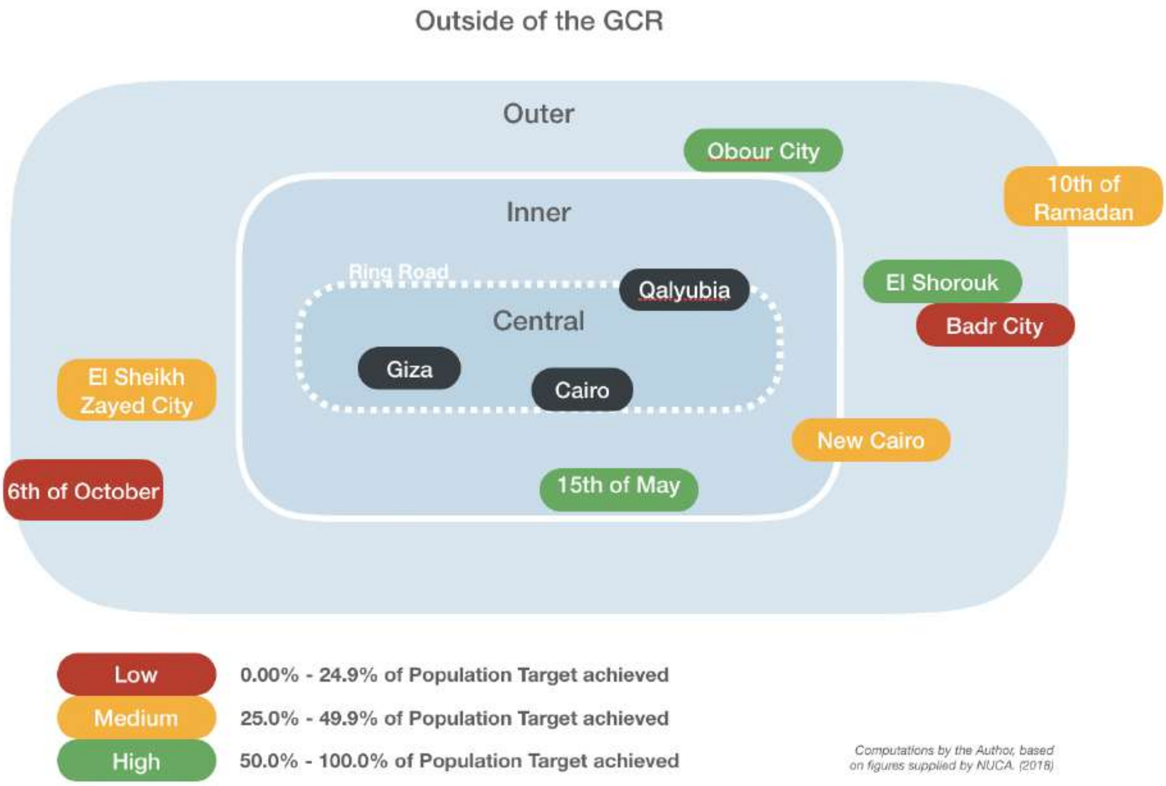


Figure 1: Schematic representation of governorates and NUCs within the Study Area

1.2.2. Planning and policy outputs

In general, there are three main levels of action to network planning, each aiming at achieving impact at a specific time horizon. Following is a description of each level and the expected/targeted results on each of those levels:

- **Strategic Planning**: Strategic planning forms the upper level of the planning process. It consists of formulating the goals and priorities that the multimodal transport network and urban mobility policies work towards, and defines the possible options for delivering this vision. It involves working at developing the network over the *medium to long run.*
- **Service Planning and Policy Formulation**: This forms the medium tier of the planning process, and consists of identifying the optimal options and proposing improvements for existing services; as well as formulating implementation guidelines for planning services. It involves working at planning services within the network and formulating high-level recommendations over the *short to medium run*.
- **Project Design and Operational Policy Design:** Project Design and Operational Policy Design forms the most concrete level of defining and designing measures and projects to achieve the targets of the strategic planning through existing networks and infrastructure, or construction of new infrastructure, addition of new services and detailed definition of operational policy recommendations. It involves translating the strategic objectives and service plans into concrete projects and operational policies over the short run.

Table 1: Network Planning overview and main focus of the present study.

	3 main network planning dimensions		
	Strategic Planning	Service Planning and Policy Formulation	Project Design and Operational Policies
Public Transport (Formal)	Objective A: 3 Key Demand Corridors		
Public Transport (Informal)	Objective C: Informal Transit reorganization principles		
Private Transport	Objective B: 10 P+R Facilities		
Active Modes	Objective D: Range of Interventions		
	Objective E: Propose Bicycle Network		
Land Use Management			
	medium to long run	short to medium run	short term

Table 1 presents a schematic overview of the dimensions of network planning; the ones highlighted in blue represent the scope of each objective of this study.

This study focuses on the strategic level planning dimension to identify three recommended corridors, and ten recommended PnR facilities. To do so, the consultant starts with identifying a shortlist of demand corridors; identifying the exact geographic boundaries and granularity of analysis; measuring accessibility at the metropolitan scale and computing an Accessibility Indicator for the GCR; ranking the shortlisted corridors to identify the three recommended corridors; and finally ranking the shortlisted group of Park-and-Ride (PnR) facilities to identify the ten recommended facilities. The majority of the analysis takes place using advanced geospatial quantitative methods. It involves aggregating multiple data sources from third parties; combining them with data provided by the consultant; utilising a host of proxies and creative alternatives to fill the gaps to compute the required datasets.

It is important to keep in mind that the outputs of Objective I and II, the choice of three corridors and ten PnR facilities, will then require a separate step of analysis to choose the most suitable corridors and PnR locations for project implementation based on land-acquisition, financial, political and other constraints. This level of analysis to plan the eventual service and design the project is beyond the scope of this study and requires a different working methodology and set of skills.

Objective III is highly complementary to Objectives I and II. Mass transit corridors and PnR facilities are highly intertwined with existing modes of transport. Informal transport could act in a complementary fashion or provide a threat to project implementation and eventual sustainability. Pedestrian and cycling accessibility to facilities has to be high to ensure that any new infrastructure is utilised optimally.

This study relies heavily on modeling, testing scenarios, and strategic planning. To bridge the gap between this level of strategic planning, and the eventual service planning and project design, the consultant believes a goal of this work to be in making the methodology and results accessible. This pragmatic approach takes multiple ways:

- The consultant tries to explain the methodology used through text and accompanying high quality visual aids, including a clear description of input data and expected outputs, as well as the associated limitations.
- Multiple layers of analysis result in single number; such as an Accessibility Score (for each area of analysis); Accessibility Indicator (for an entire region / the metropolis); Pedestrian Connectivity (for a specific point location) or the Journey Gap (for any given trip). While reductive in nature, these indices highlight complex issues in an easy-to-digest fashion.
- Diverging concerns and opposite opinions are expected in the context of urban planning; large-scale public transport infrastructure is no exception. Furthermore, each and every city presents a specific context and specific needs. Still, dealing with informal transport is an experience that many cities in Africa, Latin America and Asia underwent in different fashions. Bearing in mind local specificities; a number of recurring themes and pre-requisites for success exist. The consultant tries to balance the quantitative approach of this study with a qualitative set of high-level principles regarding the informal sector, inspired by international case studies. These principles are meant to be adaptable to evolving contexts.
- Visualising Cycling Walkshed Maps, as proposed for Objective III (C), aims to create a tool to change opinions towards globally established rules-of-thumb that are still not appreciated locally; such as the usability of bikes for the last-mile transport.
- Finally, this study includes a component of publishing not just the study openly; but a number of the associated datasets in their raw forms as well. This will hopefully enable future studies and researchers to build on it, rather than start anew.

2.2. Methodology of network planning

2.1. The user experience within urban mobility

There are many different modes of transportation for getting around the city. The choice of mode is dependant on many factors, among which are quality of service, socio-economic standing, gender and health condition of the individual, and the area in which movement will take place.

All of these modes can theoretically get you from one point to another, albeit at different times. The time it takes to complete a trip is not limited to in-vehicle time, but also includes time for pre-trip planning, walking, waiting at transfer hubs and parking. This trip anatomy is dependant on the mode of transport, as each mode will have a different combination of the components mentioned above. The range of any mode of transport is limited by time; the total trip time is a deciding factor in whether a person will have it as part of his or her regular itinerary.

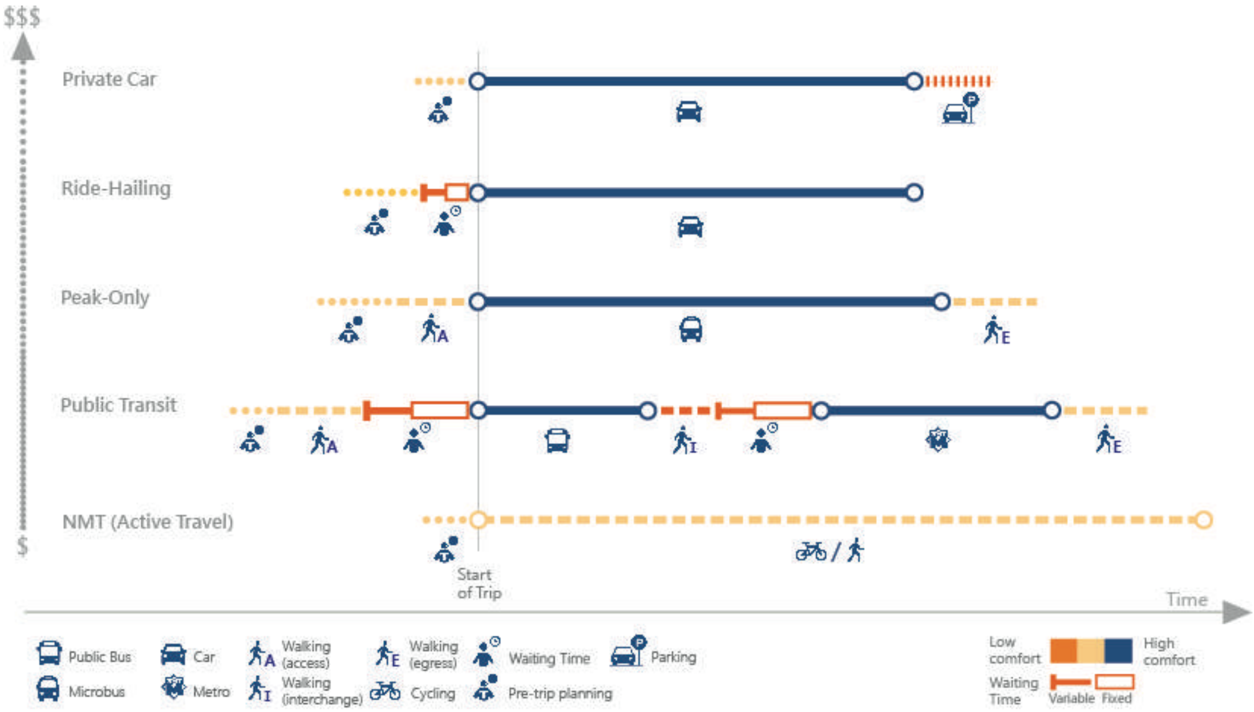


Figure 2: The User Experience, broken down by steps. Compares a likely hypothetical journey across modes by total cost (Y Axis) and trip duration in time (X Axis). Actual ranking of modes might differ.

Total trip time is very important when trying to measure how accessible the city is to its residents. People with the longest commutes have the lowest overall satisfaction with life. (Choi, Coughlin, and D'Ambrosio 2013). A one-way travel time of up to 60 minutes is a threshold most people prefer not to exceed, and one where adverse economic, health and well-being effects start to emerge. Accessibility is a measure of the range of travel enabled by a particular mode.

We focus on Public Transit as the most financially accessible mode of transport to the majority of the population. To be able to compute accessibility based on travel time using public transit, we need to have values for all the components of the trip anatomy, as indicated in Fig 2. But before we do that, we must define what constitutes public transit.

2.2. Datasets: Transport Supply and Transport Demand

2.2.1. Transport Supply

At the moment, there are many different services that provide collective transport to commuters. These services differ in nature and cannot all fall under the umbrella of public transport. They include the Cairo Metro, Cairo Transport Authority (CTA) buses, private bus and minibus operators and Informal Transport, all with different operating characteristics. Which services we add to the accessibility analysis depends on the definition of what constitutes ideal public transport. Figure 3 illustrates the full spectrum of services based on their adherence to the requirements of good public transport, as defined by Jarrett Walker (2012). *See Background Box 1 for transport modes in Cairo, and Background Box 2 for a definition of good Public Transport by Jarrett Walker.*

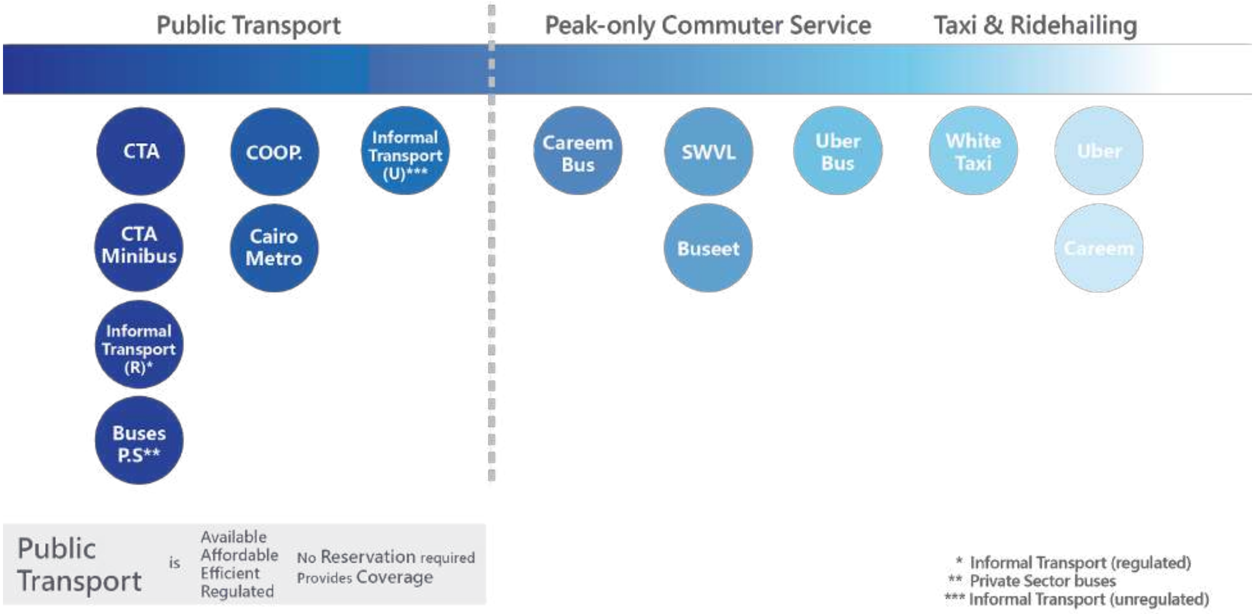


Figure 3: What qualifies as Public Transport?

Background Box 1: General Transit Feeds Standard (GTFS), the mp3 of public transit.

The available data will need to be processed into the GTFS format for analysis. GTFS, or the General Transit Feed Specification, is a common format for public transport schedules and associated geographic information. GTFS feeds are made up of text files that store information on routes, trips, fares, stops and operating schedules. In effect, they enable software to recommend itineraries and calculate the total travel time by adding up the components of the trip anatomy. A detailed explanation of the GTFS datasets used for the study is available in Appendix E

2.2.1.1. Future Transport Supply

There are also a number of public transport projects at various stages of implementation across the GCR. A breakdown of all these projects is in Appendix H.

Accounting for future transit developments would provide more accurate results when analyzing the impact of a potential intervention; the impact of a Potential Public Transit Intervention (PPTI) will differ depending on the existing transit infrastructure at the time of implementation.

We chose to include in the analysis all projects expected to be completed by 2022. These projects are added to the present scenario, and the impact of any infrastructural intervention is assessed by comparing it to this modified present scenario. Such an analysis allows us to avoid the risk of suggesting interventions that are too similar to the ones already being implemented.

2.2.2. Cities As Labor Markets - Models for Transport Demand

2.2.2.1. Opportunities (Where to)

To evaluate the current public transport system, we must analyze how effective it is at getting people where they need to go. This is usually done by estimating the demand for travel from stated preference surveys or more advanced techniques that measure demand from new telecommunications data. However, since these data are unavailable for Cairo and the most frequent commute is the one taken to work (ITDP 2019), we will use job opportunity locations as a proxy for demand.

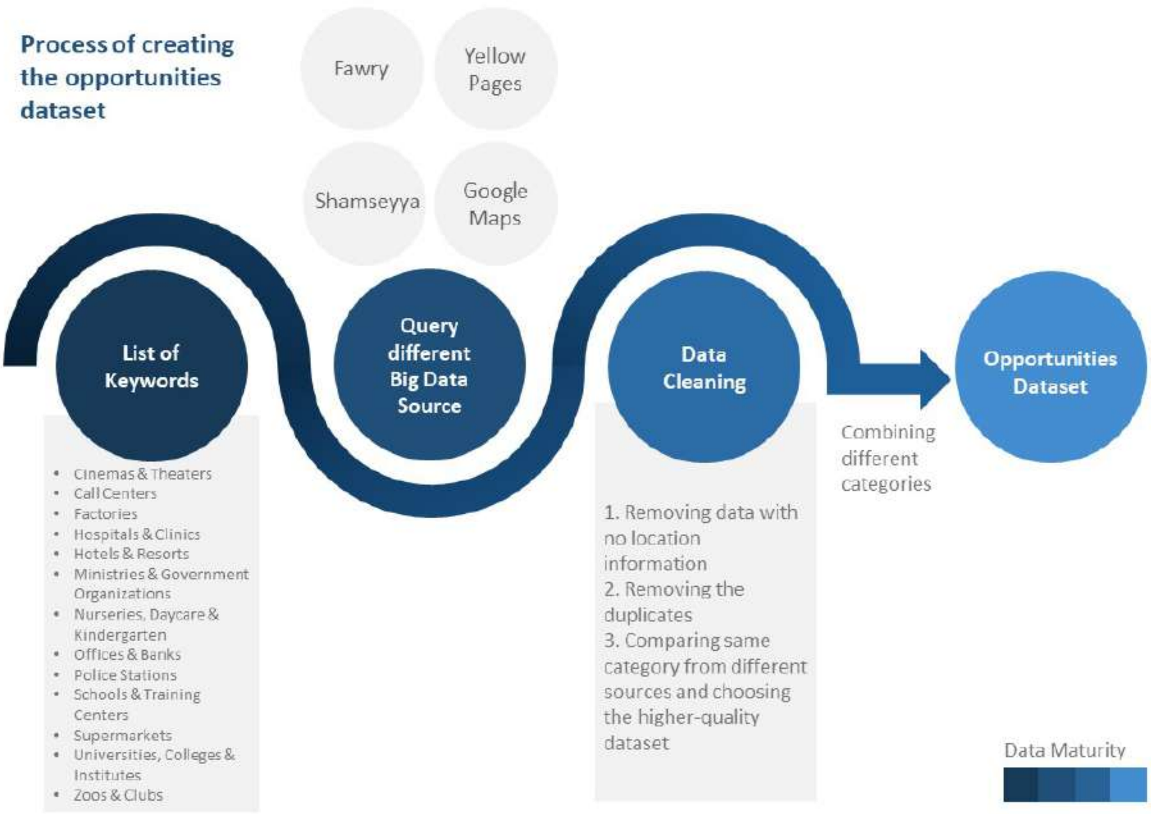


Figure 4: Opportunities processed

There is no widely used database for the GCR of where people work. To approximate demand for travel, we utilised an innovative approach to create a dataset of general opportunities. Relying on publicly accessible Big Data sources, the dataset approximates the spatial distribution of job opportunities in the GCR. Using the total number of jobs published by CAPMAS and the relative proportions of industries from the Labor Force Survey (LFS) from the Economic Research Forum, we compute the estimated distribution of jobs and thus arrive at a dataset of the locations and numbers of jobs around the city.

In order to collect the locations of opportunities from Big Data sources (Google Maps Locations API, YellowPages listings, etc.), we had to provide search terms that define the place such as market, office, etc. To produce such a list, we utilised the greatest trip generators as defined by the Institute of Transport Engineers, a widely used US code for transport engineering studies (*Travel Engineering Handbook - 6th Edition* 2009). It provides a list of highly trafficked destinations such as stores, restaurants, theatres, and zoos. As the goal in the opportunities dataset is to capture employment opportunities and not points of interest, we prioritized establishments with high numbers of employees and locations over ones with high numbers of patrons. The opportunities dataset does not capture informal employment since the total number of jobs is derived from the official reported figures. It does however, utilise other point of sale data, such as Fawry locations, to account for the unlisted and generally unlocated industries found in the LFS. The process and methodology to create the opportunities dataset is detailed in Appendix B.

2.2.2.2. Population (Where from)

Knowing where people live and how they are distributed is key to understanding the relation between where people are and where they want to go. It also has the added benefit of describing the impact of each PPTI on accessibility in terms of the numbers of people it will serve.

For our analysis, we use 2018 population figures acquired from the Central Agency of Public Mobilization and Statistics. The dataset has population figures at the level of the Shiyakha, or sub-district. We distribute these figures into smaller units of size in order to conduct our analysis. A detailed explanation of how we created our population model can be found in Appendix A

2.2.3. Ridership - Ride Hailing Data

Ride-hailing providers, mainly UBER and Careem, have proliferated in the GCR and form a main part of the transport mix. Within the local context of high unemployment and traffic congestion; ride hailing services provide a compelling solution for drivers looking for employment and commuters looking for high quality transport services.

The consultant received a sizable dataset from regional provider Careem, which includes anonymised origins, destinations, intermediary points, durations and lengths disaggregated by time-of-day and dates. This high quality dataset provides a rich source of information that is examined in section 3.3.3.

Background Box 2: What constitutes good Public Transport? A definition by Jarrett Walker.

- **It takes me where I want to go**

This deals with coverage. What is the reach of the service? Can it take me from where I am to where I want to go?

- **It takes me when I want to go**

Some services may satisfy the coverage but only at certain times of day. Higher frequencies throughout the day means people don't need to think about sticking to a schedule; the service is there when they need it. Infrequent and peak-only commuter services do not satisfy this criterion since they have limited availability and so cannot be relied on throughout the day.

- **It is good use of my time**

The efficiency of the service is also key. A connected network that allows me to travel between two points in a reasonable time will be seen as a good alternative to a private vehicle. A large gap between travel time using a private vehicle and using collective means of transport is an indication of a poor service.

- **It is good use of my money**

The cost of a service determines who it is available to. Public transport is meant to be an affordable means of transportation, but not all forms of collective transport are in the same price range. A number of new services in Cairo offer collective means of transport at prices that are targeted at high-income groups.

- **It respects me in the level of safety, comfort, and amenity it provides. I can trust it.**

The quality of a service is a determining factor for many potential users. Informal transport vehicles are renowned for reckless driving, and so are ignored by some commuters. Some services are not designed to accommodate people with disabilities while others are not convenient for women due to factors such as limited personal space.

- **It gives me freedom to change my plans**

This is tied to how the user interacts with the service. A service that requires booking in advance is more rigid; if the user changes their plans then they need to cancel their initial booking and pay a fine for doing so. A traditional service that can be waived down on the street is more accommodating to flexible plans and requires no planning ahead of time.

Source: Walker, Jarett. 2012. *Human Transit*.

These categories help us analyze the existing services to determine whether or not each one can be classified as public transport. They show a clear difference between newly emerging services and existing ones. Newly emerging services all require smartphone to use, which excludes a big section of the population. These new services are also expensive and are not a viable mode of transportation for everyone. It therefore does not make sense to include them as modes of public transport in our accessibility analysis.

2.3. Corridors Under Study

The Greater Cairo Region (GCR) includes a vast road network spanning hundreds of kms. In order to create a reasonably comparable sample of corridors for analysis, we narrowed down the main road arteries based on inclusion in past studies, coverage, geographic specifics and transit service availability. Figure 6 visualises the 19 corridors, categorized by zones covered.

Each corridor consists of multiple segments. Segments are then combined into potential public transport infrastructure (PPTI) service routes; for example possible routes for future BRTs. Such PPTIs are then modelled and analysed. By combining segments, we can model PPTIs that span multiple corridors.

Travel time and travel time deviations are analysed across segments to determine the optimal routes for PPTI. The analysis of the impact of the different PPTIs enables us to identify which corridors are best suited for intervention. The corridors are ranked according to the extent to which they are utilized by high-impact PPTI routes.

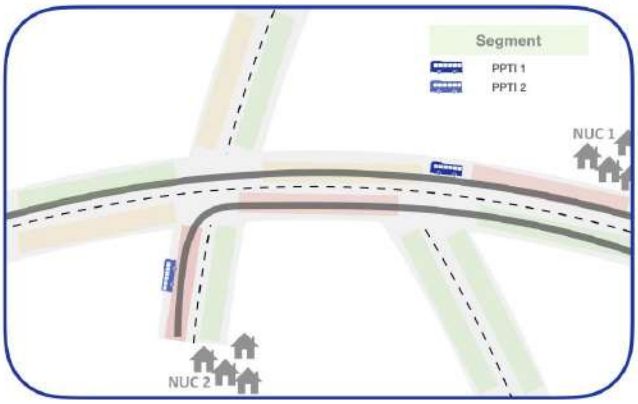
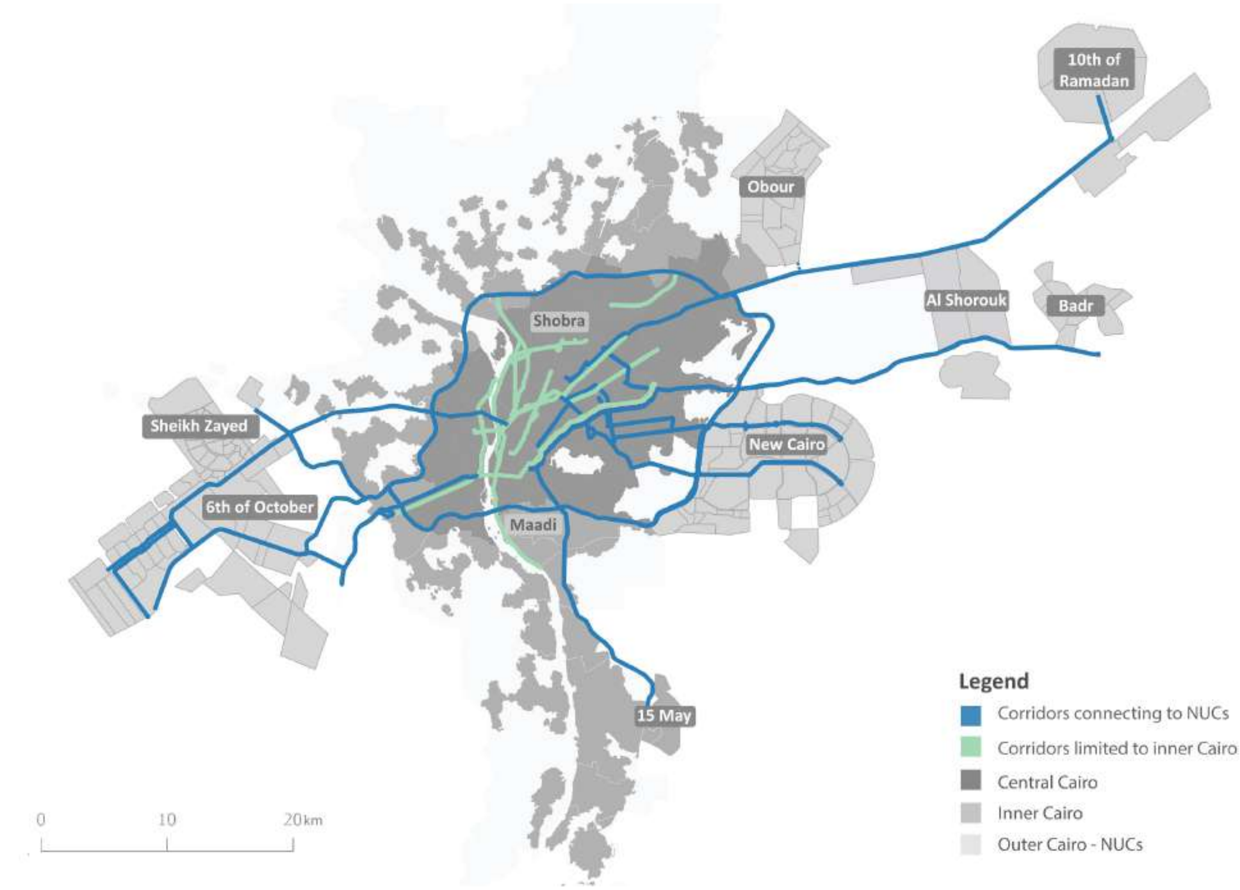


Figure 5(Top): Corridors, Segments and PPTIs.
Segment colours denote traffic situation. PPTI 2



(Please check Appendix C for a detailed explanation)

2.4. Geospatial Analytics

2.4.1. What is Cairo: Boundaries, Areas and even-sized regions

Official city borders don't always describe real-world situations accurately. The GCR includes the governorates of Cairo, Giza and Qalyubia.

These official boundaries include massive areas of undeveloped desert space, as well as remote rural districts in the Qalyubia and Giza governorates. They cover seven NUCs (15th of May City, 6th of October, Badr City, El Sheikh Zayed City, El Shorouk, New Cairo and Obour City), and exclude 10th of Ramadan city which administratively falls under the governorate of Al Sharkia.

Thus, we redefined the exact boundaries of the GCR for use within this analysis to more accurately cover the functional urban agglomeration. Within these boundaries, we removed districts and areas that we do not consider to be part of the city. These include the water surface of the nile, the uninhabited mountainous terrain around Mokattam, the patches of remaining cultivated agricultural land bordering informal settlements at the fringe of the city, and vacant desert plots around and within the NUCs.

Then we partition the research area into even-sized modular regions. This facilitates the computation of the accessibility analysis. A hexagonal system was used, with different resolutions of hexagons.

A standardized categorization is used across the report:

- **Central Cairo**, as defined as the urban agglomeration inside the ring road.
- **Inner Cairo**, as defined by the urban agglomeration outside the ring road.
- **Outer Cairo** and all **NUCs** as defined using their administrative boundaries.

Appendix A explains in detail the choice of boundaries, areas of study, criteria for excluding areas, and goes into more detail about the hexagonal grid system chosen for this study.

Appendix F explains in detail the Methodology for computing accessibility.

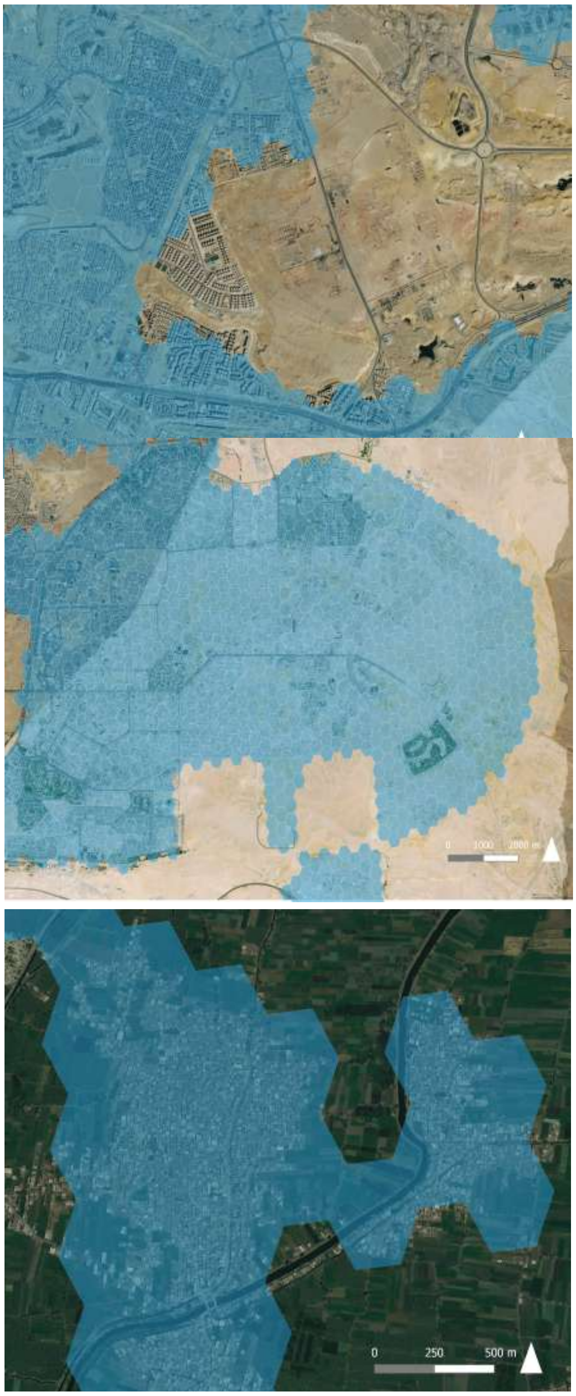


Figure 7: (Hexagons overlayed on urban areas, excluding agricultural and desert land.)

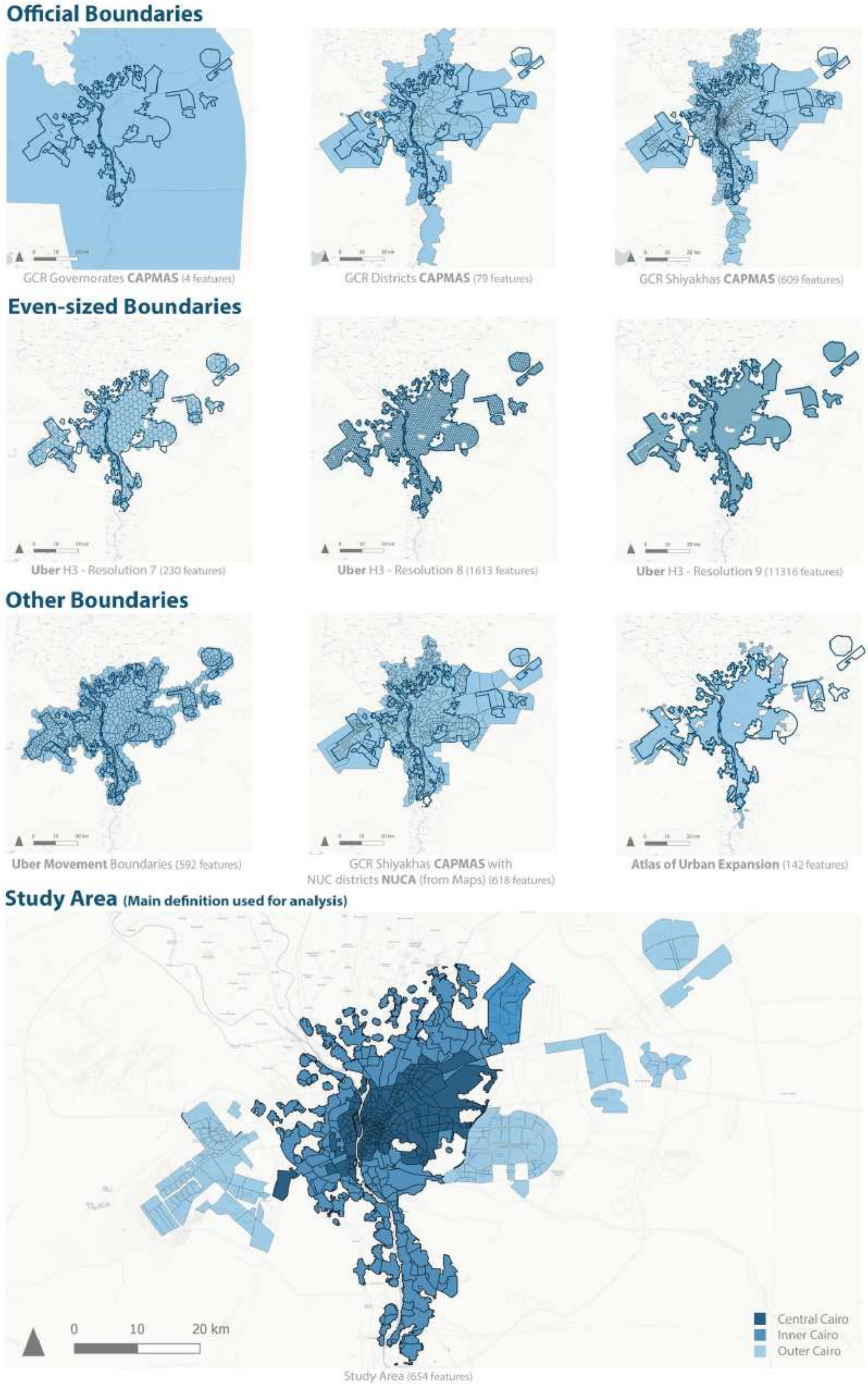


Figure 8: Boundaries Layers

2.4.2. Traffic Congestion

The quality of the network is best understood through the efficiency with which a vehicle can travel on it. This efficiency can be best captured using three indicators: Congestion, Average Speed and Commuting Time Predictability.

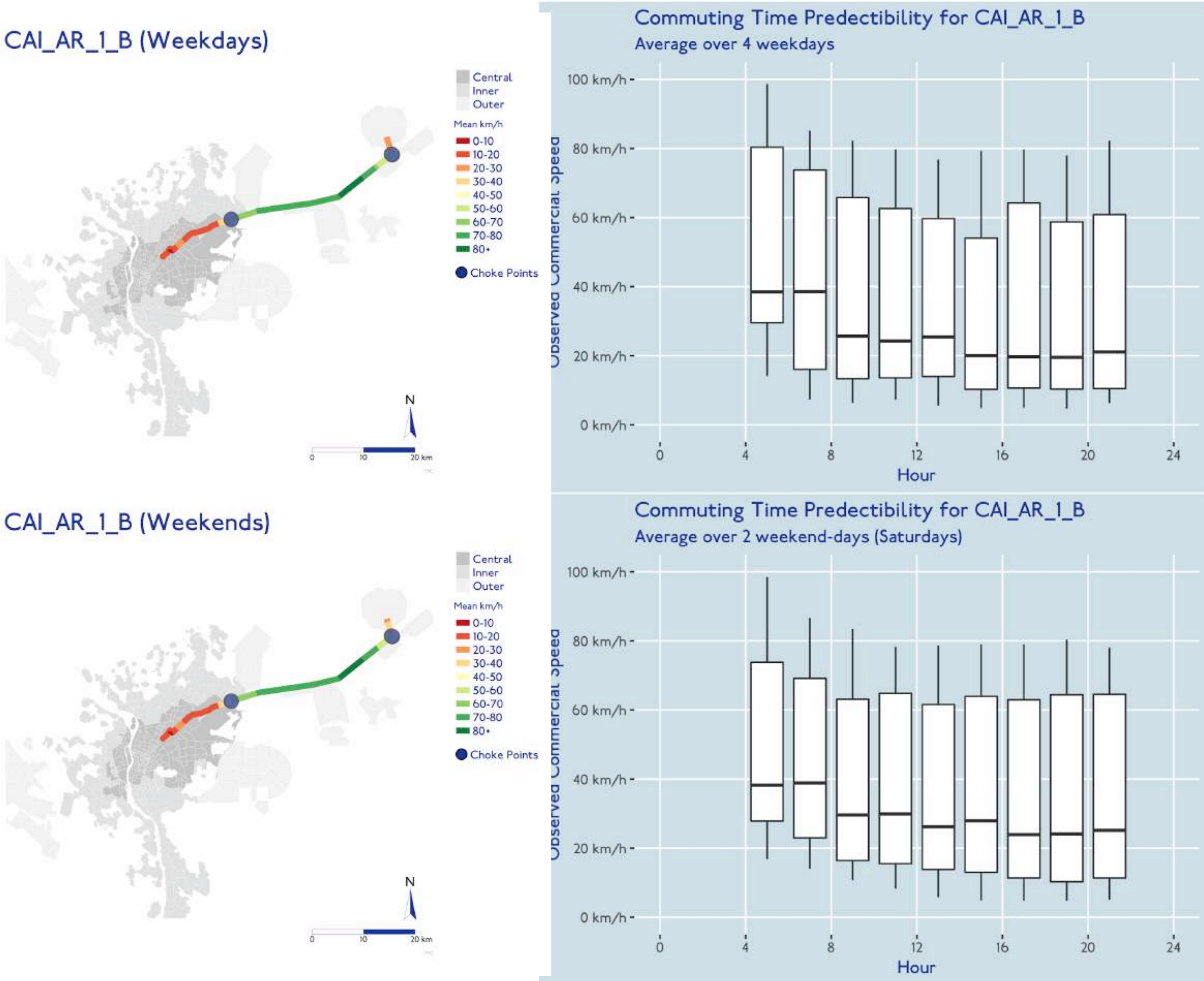


Figure 9 (left): Itinerary of the 'El Qubba Bridge - 10th of Ramadan City' corridor, including mean Speed of vehicle traffic [km/h] and chokepoints. The direction is eastbound (Weekday/Weekend). (Right): Box-plot of commuting time predictability (Weekday/Weekend). We see a relatively high average speed (~ 40km/h) before 8 AM in the morning and then a midday slow period to around 30 km/h on weekends and 20 km/h on weekdays as expected.

Traffic congestion along the corridors can tell us which segments are operating beyond their capacity and most in need of an intervention. Average Travel Speed directly affects the accessibility enjoyed by users of a particular corridor. Predictability of Commuting Time indicates the level of fluctuations in demand, and the quality of the traffic management.

Figure 9 visualises the itinerary of the 'El Qubba Bridge - 10th of Ramadan City' corridor, and the average travel speed for private vehicles across the entire data collection period to date. It also plots the distribution of observed travel speeds across the lengths of the corridor by hour using a white box plot. Figure 10 plots the average speed across the 65km length of the entire corridor broken down by weekday / weekend. This allows a more analytical identification of (a) chokepoints across the corridor, (b) changes in commercial speed across hours of day and (c) distinct patterns for weekdays vis-a-vis weekends. This clearly shows the relationship between time in the day and commercial speeds, indicating congestion.

Choke points or congestion hotspots are the locations across each corridor where there is the biggest change in congestion before and after passing through them. This analysis would start with looking at averages and outliers, and be followed up with a detailed temporal analysis for each potential chokepoint. Some gridlock situations are due to narrow spots, and require priority for public transport. Other situations are mainly due to excessive demand at particular points of time. The accompanying 'Travel Time Analysis' Document will look at this in more detail.

This analysis is repeated across all corridors and is based on quantitative and qualitative methods to identify geographical choke points and peak travel times. Choke points will be the basis for choosing the location of Park and Ride Facilities near the terminals of the Key Bus routes. They are identified as the general location along a corridor where the average speed switches from smooth driving to stop-and-go traffic. It is chosen to be around 40 km/h and indicated in yellow in Figure 9 above. The methodology for the data collection is explained in more detail in Appendix C.

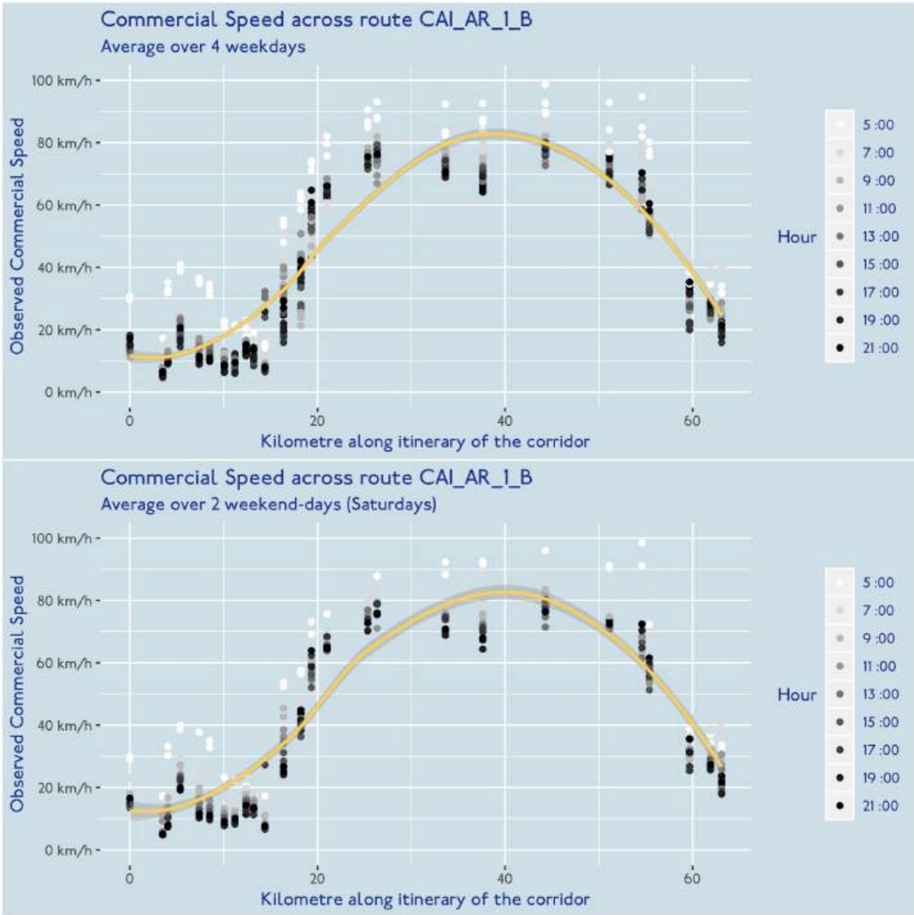


Figure 10: Observed commercial speed along length of itinerary (Weekday/Weekend)

2.5. Accessibility Analysis

Accessibility measures what people can reach given temporal, financial, and individual constraints. Martens (2017) claims that transport projects are often evaluated using easy to measure metrics such as travel time which favors mobility (the movement of people) over accessibility (the ability to reach destinations of value). He also suggests prioritizing the improvement of access to those whose access is low to begin with because of the law of diminishing returns. Those whose accessibility is high to begin with will not benefit as much from one unit of improvement than those whose accessibility is low.

In our implementation, we focus on the employment opportunities within one hour of travel on public transit. This includes jobs, schools, hospitals or any other destination. It requires knowledge of both the current transit schedule and the potential destinations. An accessibility analysis does not measure the actual travel patterns of people, but their potential ones; what they could do, not what they actually do. This helps count the number of opportunities the resident of a particular area can reach in a reasonable amount of time.

Employment tends to be responsible for the highest frequency of daily trips. In our analysis, Accessibility will be calculated by measuring the number of employment opportunities (as explained in '2.2.3. Transport Demand') available within one hour of travel using public transport. Travel time is computed by summing up all components of the user experience within urban mobility, incl. Total walking time to (Access), between (Interchange) and from (egress) modes of transit. This is done on three levels:

- **A single point analysis:** We identify a particular origin, and calculate the number of opportunities that are accessible across the city. *We create a matrix with every area within the NUCs as an origin, and perform a single point analysis for each.*
- **A regional analysis:** We replicate the single point analysis for every area. We *group the areas by NUC, creating a regional analysis / accessibility metric by NUC.*
- **A weighted regional analysis:** We weigh the results of the regional analysis by the population of each area survey, yielding a weighted NUC-specific average accessibility score.

The final step is to create an Accessibility Indicator for the entire study area. This is one figure that reveals how Accessible opportunities are to residents of the metropolis. It is a figure that can be used to compare the GCR to other cities around the world. The detailed steps of the analysis are included in Appendix F.

The role of gender in affecting the Accessibility Analysis

Understanding gender differences in transport accessibility is important to implement gender-sensitive projects. A smart understanding of gender includes data on mode of transport acceptability (of transport to traveler's standards), safety, adaptability (accessibility to washroom, option to purchase two seats, etc.) and other factors. Gender based violence reduces women's ability to move freely in the city; reducing their actual experienced accessibility. External factors (urban environment design, perception of safety, societal norms, etc.) further affect women's travel behavior. Currently, very little gender sensitive data on women's accessibility is available in Egypt. This Accessibility Analysis was therefore designed to be gender neutral. Results should thus be interpreted accordingly, and limitations acknowledged and acted upon.

2.6. Ranking Corridors and PPTIs

The 3 Key Demand Corridors (PPTI routes) are chosen through a mix between a quantitative and a qualitative assessment of the transportation situation in Cairo. The choice makes use of diverse sources of primary and secondary data to identify population estimates, locations of job opportunities, demand for mobility from ride-hailing data, supply of public transport routes both formal and informal, and finally the areas of low accessibility to jobs in the city.

The quantitative ranking is based on the following criteria in decreasing order of importance:

- Improved accessibility to jobs
- Decreased travel time to the central business district to quantify time saved
- Improved service coverage
- Interchanges with Cairo metro

This leads to a qualitative review of all the existing corridors. While all 19 corridors (CAI-CAI, CAI-NUC, NUC-NUC) are analysed; only the nine (CAI-NUC and NUC-NUC) corridors are considered as potentials for the future PPTI intervention. Nine scenarios for PPTI's are then chosen by editing the original corridors into more suitable route for potential public transport investments.

This metropolitan accessibility analysis will be computed for the present situation using GTFS feeds that depict the 2019 public transport network in the NUCs and the GCR. It will then be performed for future potential scenarios; computing the resulting accessibility improvement of each scenario.

This process will be repeated for each of the nine PPTI's in our study. The improvement of accessibility is measured separately for each scenario. The PPTI scenarios yielding the biggest gains in accessibility are then ranked and identified. They are analyzed quantitatively to assess:

- Contribution to a metropolis-wide vision[2] for managing public transport. The vision is a narrative that is derived from the aforementioned sections on (a) Population distribution; (b) Population density; (c) Opportunities distribution; (d) Opportunities density; (e) Roles of Public Transport and (f) New Expected Transport Infrastructure.
- Route structure, and being direct and not circuitous or deviating
- Making use of choke points along the corridors. Chokepoints are the few places where you can cross a barrier (i.e. a water surface, mountain, or in the GCRs case undeveloped desert land) and they tend to be congested. Having public transport infrastructure with right of way at such chokepoints would improve travel time significantly. (Walker, 2012)
- Serving distinct areas in the city, east, west, north or south and not being exclusively focused on one area.

[2] The public transport vision for inner cairo prepared in the COWI Planning Report was considered as a source in the metropolis wide vision.

2.7. Determining Park and Ride Locations

Park and Ride (PnR) facilities are meant to encourage commuters to leave their cars and resume a journey using public transportation. They help avoid congestion in the downtown area by reducing the number of cars that enter it. Factors to be considered in their location include proximity to residential areas, travel demand, and land value.

Background Box 3: What makes a good Park and Ride (PnR) facility

PnR facilities are normally located close to residential areas and far away from employment areas ("State Park-And-Ride Guide" 2012). Doing so minimizes time travelled using cars and ensures that commuters only spend a small portion of their trip driving. The stressful commute is a powerful incentive, and is only realized if reliable transit services (high frequencies and fast travel times) provide the ride component. Locating the facilities before the congestion zones and having services with right-of-way passing through them increases their appeal and ensures higher patronage.

To choose the optimal locations for PnR facilities, we focus on the corridors utilized by recommended PPTI routes and future mass transit (as documented in Appendix H). Traffic patterns along these corridors are analyzed and locations close to the beginning of congestion zones are shortlisted.

The geographic focus is on the NUCs, as the longest commutes are those between the NUCs and Central/Inner Cairo. The NUCs also have lower population densities and more empty spaces, with lower land values and higher availability than in central Cairo. PnR facilities are logical interim uses of land in such cases, as they attract commuters in early phases of development (Walker 2014). As dense, transit-oriented development begins to emerge in the NUCs, these facilities should transform into traditional transit hubs, with the highest source of ridership coming from collective forms of transportation. This is taken into account when determining PnR facility locations.

We determine where the top pick up and drop off areas for ride-hailing services are, distinguishing between short trips within the NUC, and long-term connecting them with other NUCs or Cairo. The objective is for ride-hailing users to combine a brief ride with a high quality PPTI trip to avoid mono-modal trips in favor of multimodal itineraries.

The PnR facilities must thus first and foremost contribute to the aforementioned metropolis-wide vision for managing public transport, and play a part in (1) reducing the travel distance of car users, (2) motivating car users to take ride-hailing or local public transit networks to intermodal facilities and (3) increasing ridership of the PPTI. The choice of the potential PnR locations will take place at the NUC level, and at the edges of the congestion zones of the major corridors. The walking and cycling catchment areas of potential PnR facilities is taken into account in the selection process.

2.8. Covering the full user experience: Integrating walking and cycling in planning

Active travel, known as non motorized transportation (NMT), is a necessary component within every public transit trip. Walking is the last mile solution that connects people to and from their points of interest. Facilitating the walk to a transit hub increases the likelihood of people using public transportation over private vehicles.

First, we must understand the problems that discourage people from utilizing sidewalks. Calculating pedestrian connectivity for transit hubs across the GCR helps develop a broad understanding of which regions lend themselves well to walking and which do not. A quantitative assessment of the ease of walking in a particular area compares the straight line distance with the street network distance from a point of origin. A small ratio in areas with small blocks and frequent intersections makes walking easier compared to areas with long unbroken stretches of road.

Quantitative measures often do not tell a complete story. Walkability issues are closely tied to the intricacies of both the built environment and human psychology. High pedestrian connectivity indicating a particular itinerary to be within reasonable walking time does not mean that people would be comfortable walking it. It is imperative to focus not only on distance, but on what travellers are comfortable with. We visually inspect and identify different experiential problems that are common around selected transit hubs.

Walking quickly ceases to be a practical option in suburban environments like the NUCs due to long distances. Thus, cycling is analyzed as a viable alternate mode of Active Travel. In such cases, cycling increases the area accessible within a reasonable commuting time. It is therefore our goal to ensure that the transit hubs or park and ride facilities be efficiently and comfortably accessible to both pedestrians and cyclists, not only motorists.

3. 3. Core findings and observations

3.1. Life in Cairo

3.1.1. Where do Cairo's Citizens live?

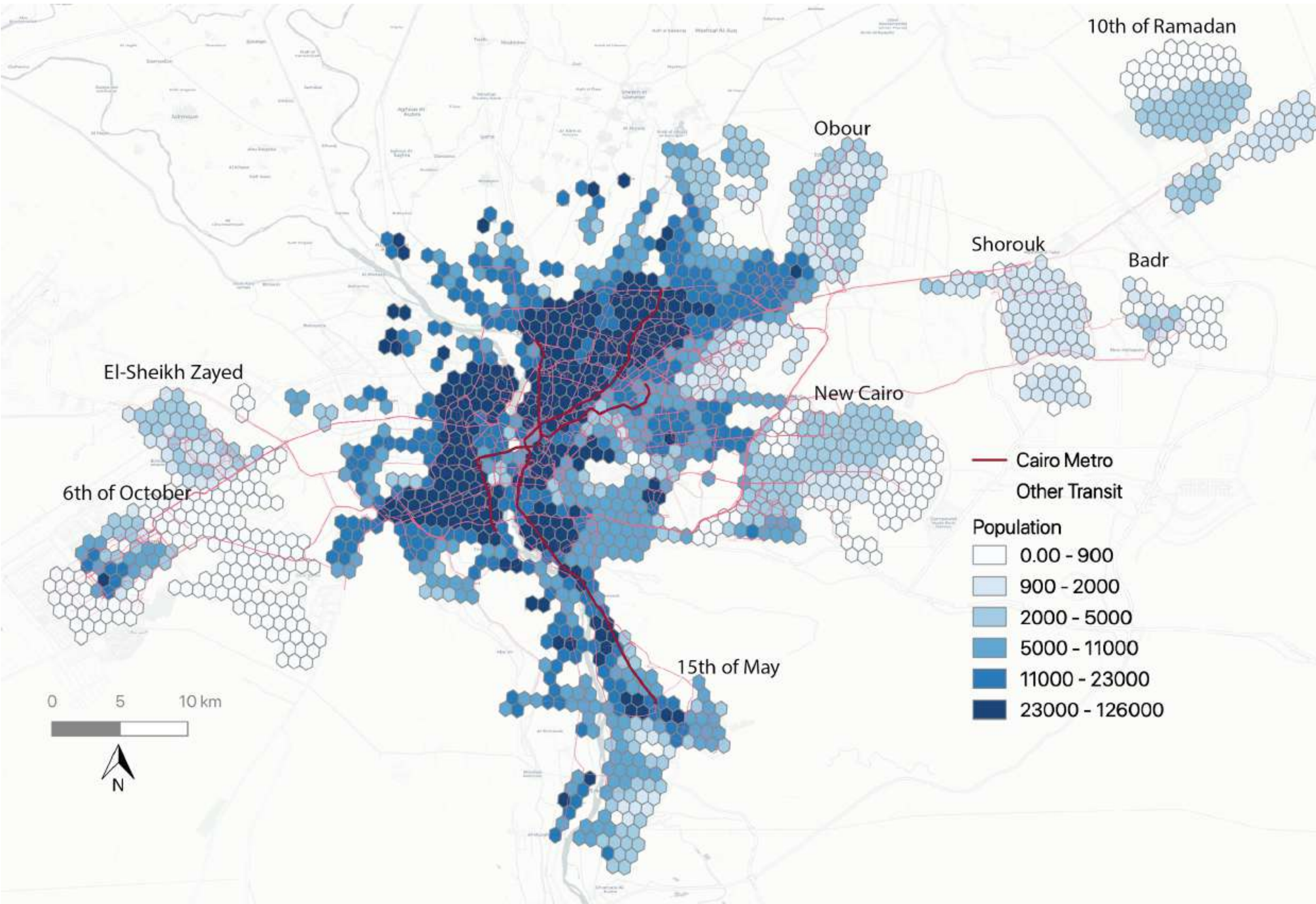


Figure 11: Population Density of the GCR on H3-8 Hexagons. High density is achieved mainly in central GCR and in some parts of the largest NUCs (6th of October and New Cairo). Data Source: TfC Population Model using CAPMAS 2018 data.

How many people live in the GCR? Where do they live? Computing population numbers is a daunting process, and subject to multiple limitations. The boundaries of the city are unclear and constantly changing; administrative boundaries do not include many parts on the periphery which are essentially part of the GCR. Furthermore, agglomerations such as the GCR often serve as centralized labor markets and attract sizeable numbers of out-of-city workers who commute and spend their waking hours within the city. Thus "daytime population" tends to be substantially more concentrated than corresponding "residential population" or "night-time population".

Existing estimates for the residential population of the metropolis include:

- 2018 figures published by the United Nations cities data booklet, which estimates the GCR to be the world's fifth largest urban agglomeration with a population just over 20 million. It estimates the GCR to grow by 5 million inhabitants to 25.5 million in 2030 (UN-DESA 2018).
- Egypt's national statistical agency, the Central Agency for Public Mobilization and Statistics (CAPMAS), estimates the 2018 population of the governorates that make up the GCR, including their rural areas, to be 24.1 million

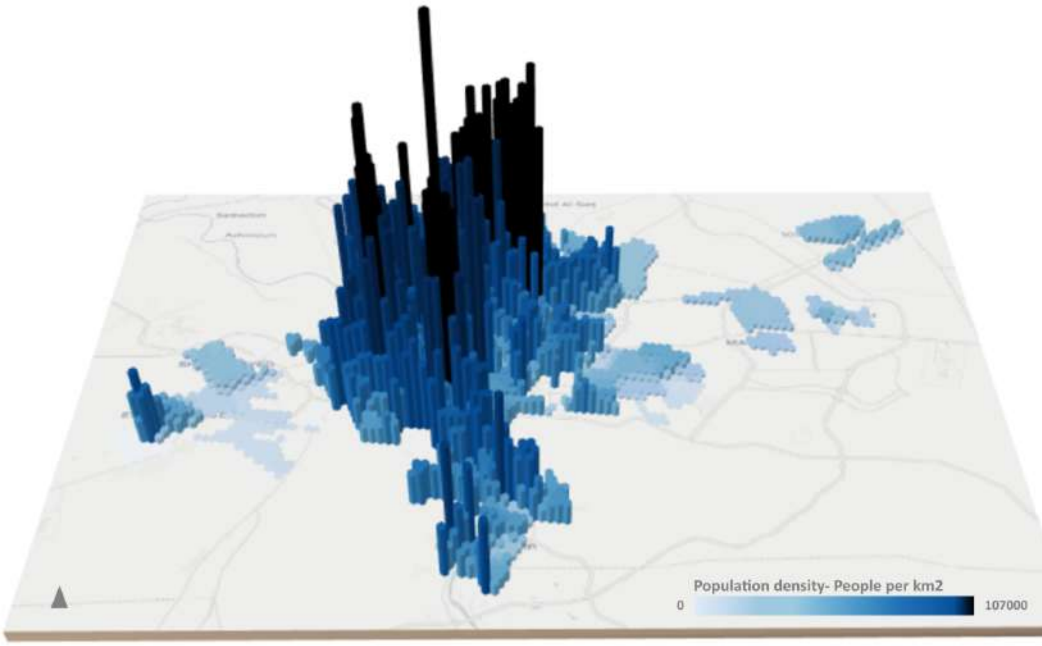


Figure 12: 3D Distribution of relative Distribution

Data: TfC Model using CAPMAS 2018 data.

The variation between the two figures is due to a difference in methodology: The UN focuses on the Urban Agglomeration, which is the "population contained within the contours of a contiguous territory inhabited at urban levels of residential density" (UN-DESA 2018), whereas CAPMAS focuses on administrative boundaries, which tend to also capture residents of areas that are not densely populated.

For the purpose of this study, we created a Population Model that covers only the areas previously defined as the boundaries of the GCR. Appendix A explains in detail the Methodology for distributing population across the even-sized Grid System.

Table 2: The densest ten hexagonal grid areas within the GCR.

Polygon Location	Density [persons/km2]
Dar El Salam	106870
Bolak El Dakror	81072
Ain Shamas	74809
Hadaek El Koba	74233
El Mataria	71041
El Talbia	68536
El Ameeria	64934
El Bsateen	64575
El Zawia El Hamra	63603

The choropleth map in Figure 12 shows the population density in different parts of the city. The densest regions occur in the inner and central parts of the GCR. This is confirmed against local knowledge of the density of the areas by observation. The top ten most densest distinct polygons are listed in Table 2 with their location.

Population figures are more problematic in regards to the NUCs. There is a big difference between the 2018 population figures released by CAPMAS, and the updated population estimates for NUCs publicly available on the website of the New Urban Communities Authority (NUCA) (referred to as "NUCA Population Count 2018",

Table 3), responsible for the management of the NUCs. The CAPMAS figures potentially undercount citizens of the NUCs as they are based on citizens registration in National IDs. Often, residents of NUCs who migrated from other parts of Cairo or Egypt do not update them immediately after moving. If at all, they are updated during renewal of the national ID, which are due every seven years. This introduces a national lag when it comes to registering residents of NUCs.

Table 3: Population estimates for the GCR, by source. The definition utilised in this study is in blue.

Population	Year	Methodology
17,744,384	2006	Census 2006 (CAPMAS) for GCR Administrative Boundaries
19,834,483	2010	Census 2006 + natural Growth (CAPMAS) for GCR Administrative Boundaries
19,264,000	2010	Worldpop 2010, clipped by the District GIS provided by CAPMAS
21,596,090	2014	Census 2006 + natural Growth (CAPMAS) for GCR Administrative Boundaries
22,178,624	2015	Census 2006 + natural Growth (CAPMAS) for GCR Administrative Boundaries
21,969,528	2015	Governorates GIS 2015 provided by CAPMAS
21,969,528	2015	District GIS 2015 provided by CAPMAS
19,493,463	2015	District GIS 2015 (CAPMAS), clipped by the Atlas of Urban Expansion (Angel, S.)
23,884,247	2017	Census 2017 (CAPMAS) for GCR Administrative Boundaries
20,076,000	2018	National Sources, as determined by UN-DESA
20,486,594	2018	Census 2017 + natural growth (CAPMAS), clipped by the Atlas of Urban Expansion (Angel, S.)
24,117,541	2018	Census 2017 + natural growth (CAPMAS) for GCR Administrative Boundaries
25,517,000	2030	Estimation by UN-DESA made in 2018

Table 4: Population figures for the NUCs, by source. The definition utilised in this study is in blue.

NUC	Pop (CAPMAS, 2015)	Pop (CAPMAS, 2018)	Pop (NUCA, 2018))
6th of October (1979)	184,373	355,616	2,100,000 11,000,000 (2040)
New Cairo (2000)	145,169	302,926	1,500,000 4,000,000
10th of Ramadan (1977)	154,007	226,953	650,000 2,100,000 (2032)
El Sheikh Zayed City (1995)	35,670	92,457	330,000 675,000
Badr City (1982)	19,828	31,877	160,000 650,000
Obour City (1982)	52,440	133,102	550,000 600,000
15th of May City (1978)	105,569	95,313	250,000 500,000
El Shorouk (1995)	26,099	88,909	250,000 500,000 (2022)

Recently published figures by CAPMAS on NUC residents register an increase. However, they remain a small fraction of NUCA figures. Spatial demography in Egypt is explained well by two features identified by David Sims: *Density* and *Interconnectivity*. They result from topography and are persistent over time. Since the 1980's internal migration in Egypt is relatively limited: "The World Average internal migration rate as a share of working class population is 15%, while in Egypt it is only 8%." This contrasts with popular imagination. Most citizens continue to choose to locate at the fringes in Cairo rather than in the NUCs. Reasons include the high interconnectivity of social networks and the spatial accessibility afforded by density.

Background Box 4: What would Cairo look like if it's NUCs reach target capacity?

For the purpose of comparison, the consultant created a dataset merging the CAPMAS Census 2015 data with the NUCA Population Count 2018 figures. The idea is to keep the total population count of the GCR within the level reported in the CAPMAS Census 2018 totals for the GCR; while spreading NUCA Population Count 2018 population figures over the NUC's area units and estimating migration from inner and central cairo to be uniform.

The additional population expected to have relocated to the NUCs was distributed over the NUC's based on three criteria of equal weights:

1. Existing population distribution in 2015
2. Area
3. Distribution of Pedestrian Commerce Opportunities (Fawry)

The result is visualised in Figure 13.

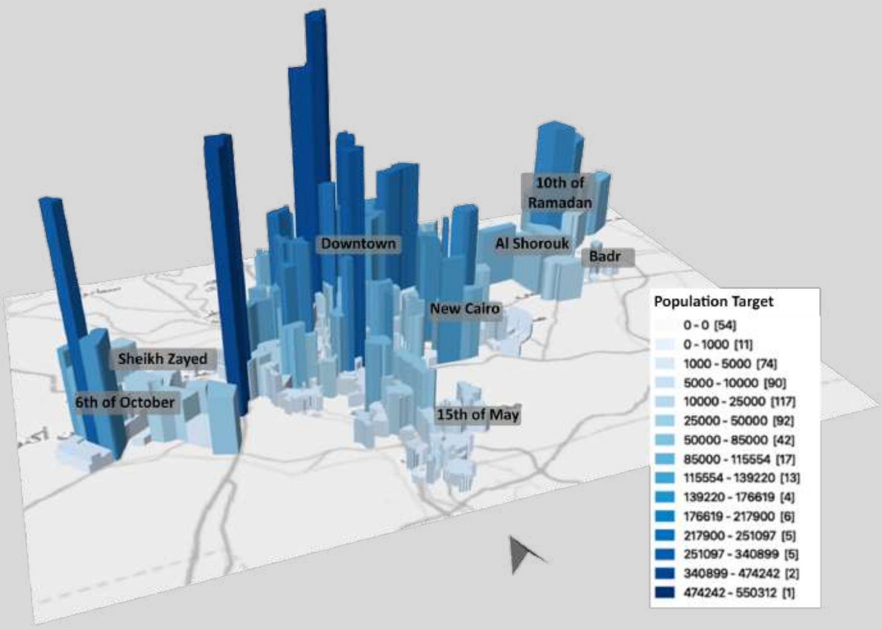


Figure 13 : Population by Shiyakha Model incorporating NUCA estimates

The population of District 6 in 6th of October would be expected to equal that of the most populated neighborhoods of Cairo: Hadayek Al-Ahram, Shubra Al-Kheima and Imbaba. In total, the residents of the GCR would still be distributed fairly densely around a dense urban core, with an eastern center, and a western center distributed over 10th of Ramadan, Obour and El-Shorouk. This image is much more striking once one considers that the current modelled figures by NUCA only represent a fraction of the final target populations. At present, CAPMAS reports 1,327,153 citizens to live in the NUCs, or 23% of the figure published on the NUCA website.

3.1.2. Comparison with other cities

The GCR stands out as one of the densest urban environments on the globe. A comparison across other cities using standardized visualisations[3] of people living in each square kilometre of a 100 x 100 kilometres urban region highlights differences: London has one of the lowest maximum and average residential densities due to its capital-intensive public transport network, enabling millions of workers to commute in and out of the central area on a daily basis. In Dar El Salam, coordinated urban growth can be traced along the Bus Rapid Transit Corridor linking the cities' west with its eastern center. This lies in strong contrast to the uncontrolled sprawl experienced by many other cities, particularly in Africa.

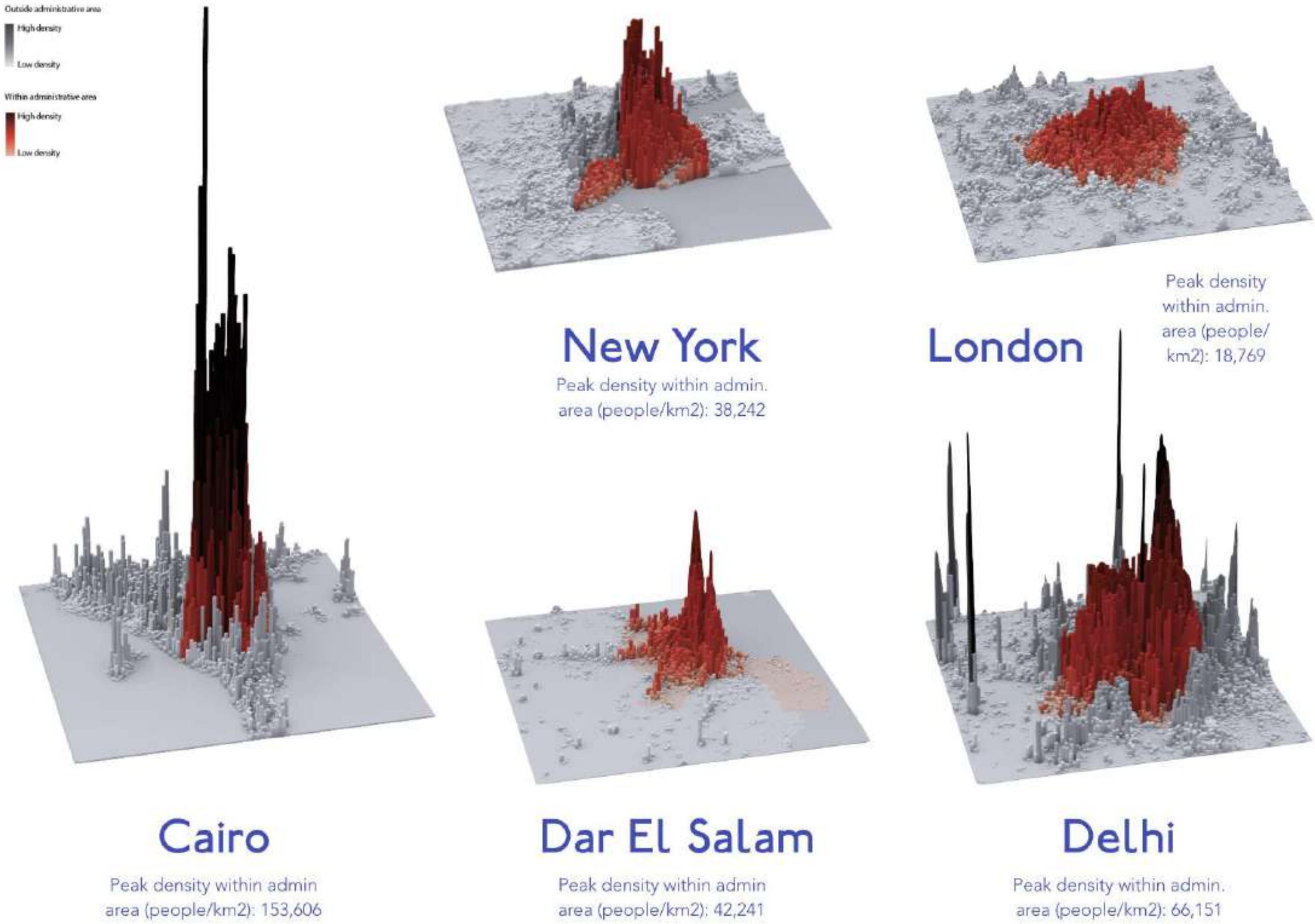


Figure 14: Comparison of Density across multiple cities. (Data Source: World GHS population grid dataset, 2015 - Data Visualisation by LSE Cities.[4])

[3] This population estimate is based on a global model produced by the Global Human Settlement Layer (GHSL) project. Such global models excel to compare across cities and borders, but are not recommended for within city analysis.

[4] "LSE Cities. Residential density, Cairo, New York, London, Lagos, Addis Ababa (December 2018), accessed 25th January 2019 https://LSECiti.es/u36cc1326."

3.1.3. Where are Cairo's Job Opportunities?

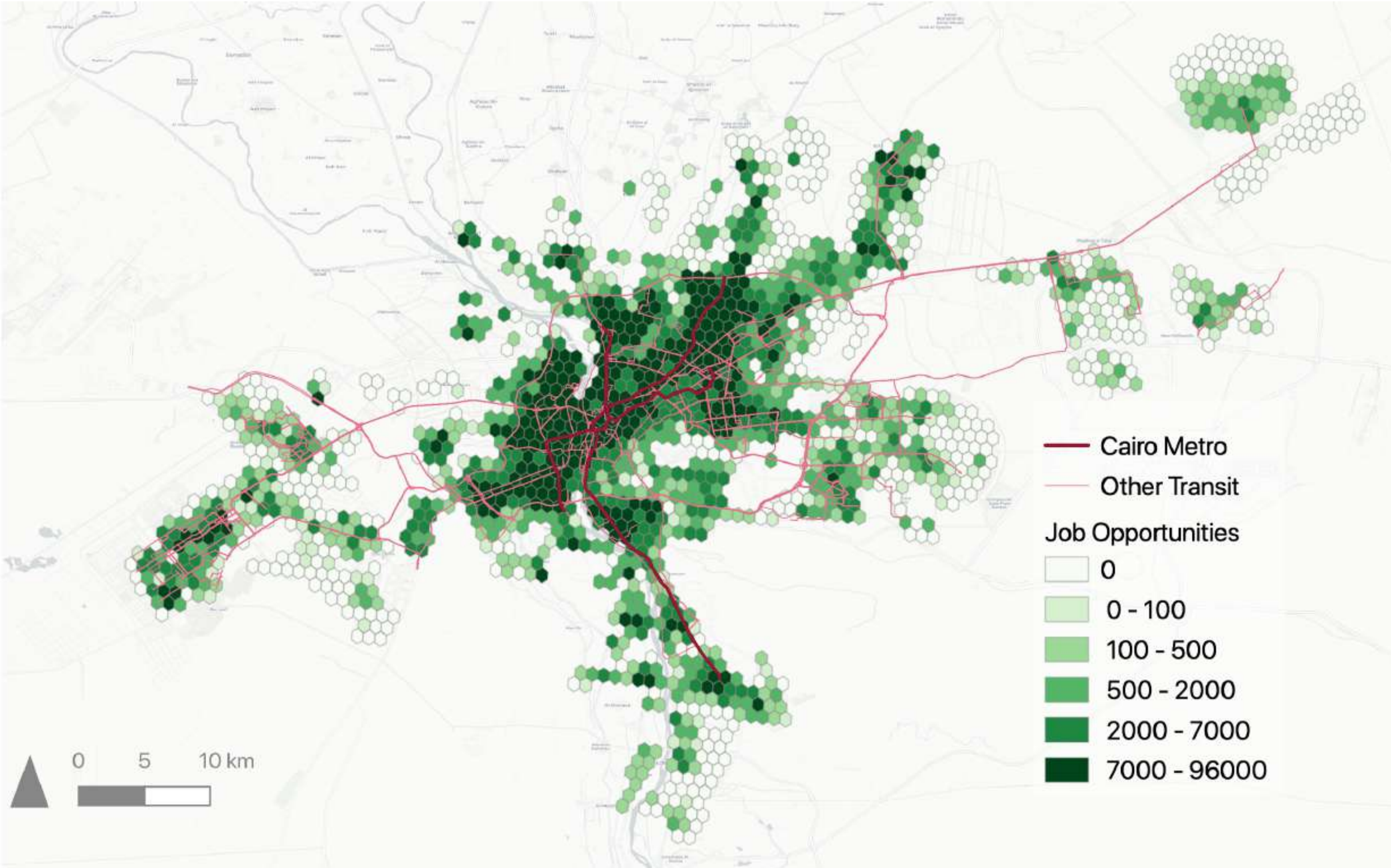


Figure 15: Job Opportunities Density of the GCR. Data: TfC Spatial Employment Model using TfC Opportunities dataset.

Observing the distribution of job opportunities across the GCR, it is immediately clear that they are highly concentrated in Central Cairo. Central Cairo remains the main Central Business District in the GCR, with the opportunities density being higher than the residential density.

This highlights the need for an integrated transportation network linking Central and Inner Cairo to the NUCs. The highly centralized employment opportunities require a high level of radial commuting into and out of Central Cairo. This becomes more necessary every year, with the NUCs population increasing and still far off their target population.

Failure to do so would reduce access to opportunities. City expansion without efficient transport to serve the periphery can lead to a fragmentation of the labor market; the jobs across the city become accessible to a smaller fraction of the population, making the city unable to fulfill its economic potential (as explained in Background Box 5).

Looking at the NUCs, it is clear that they provide little economic opportunities in comparison to Central and Inner Cairo. 6th of October, New Cairo, and the 15th of May cities are only beginning to show signs of economic activity, indicating the future growth of secondary CBDs in these cities. This zoomed out analysis is not enough to give meaningful insight on each NUC. To do so, it is necessary to go down to the city scale. This would allow us to observe each NUC independently and determine where the local CBDs are and how the population is distributed around them.

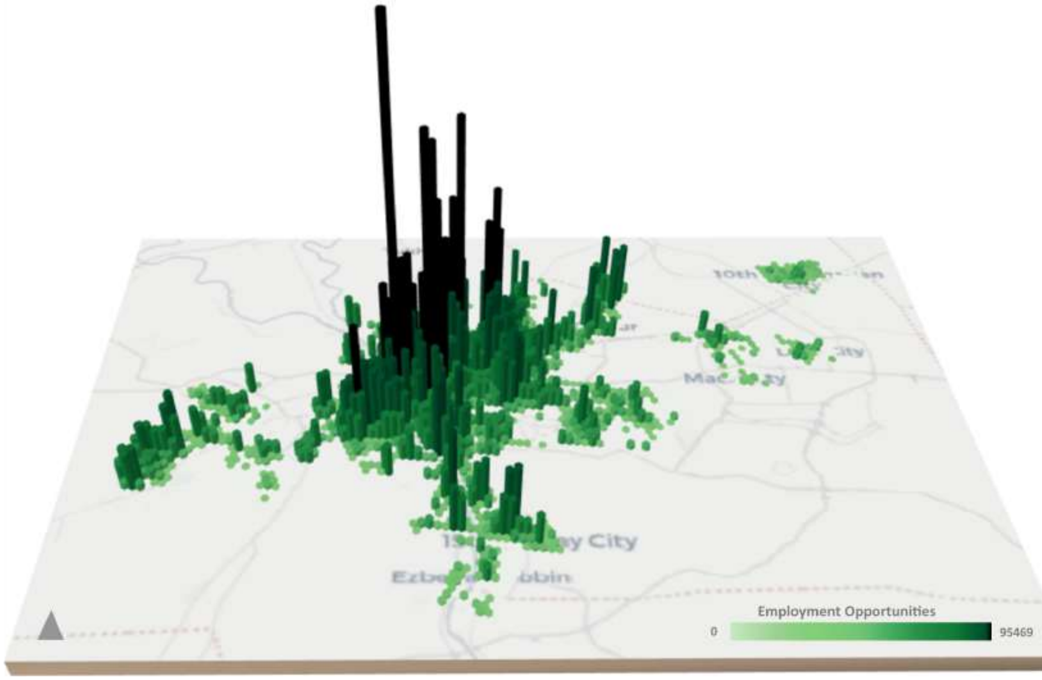


Figure 16: 3D Visualization of Job Opportunities Density Across the GCR

Background Box 6: What makes for efficient labor markets?

One defining characteristic of cities is the labor markets that they give rise to. Labor markets drive city growth. The larger the labor market, the more efficient it is. Yet, labor market size is not determined by the number of people in the city. It is the number of jobs that people have access to within a reasonable time period. This access is dependent on both commuting time and cost, and so the more efficient a public transport network is, the closer the labor market is to its potential.

The transit network serving a city should be designed to counter the spatial fragmentation of labor markets. It should allow all residents to reach all locations where jobs are offered within a reasonable commuting time.

The spatial patterns of urban mobility are based on the characteristics of the city. The different models are:

Monocentric Model

There is one Central Business District (CBD). Commuting patterns are all directed radially to and from that CBD. The concentration of a unified labor market leads to higher efficiency.

Polycentric Model

People cease to commute solely to one CBD, and gravitate towards multiple (poly) centers. New centers are enabled through good transit, and maintain a unified labor market.

High private car ownership, cheap land on the outskirts of the city, and insufficient rail-based transport to accommodate daily travel to the CBD encourage early polycentricity.

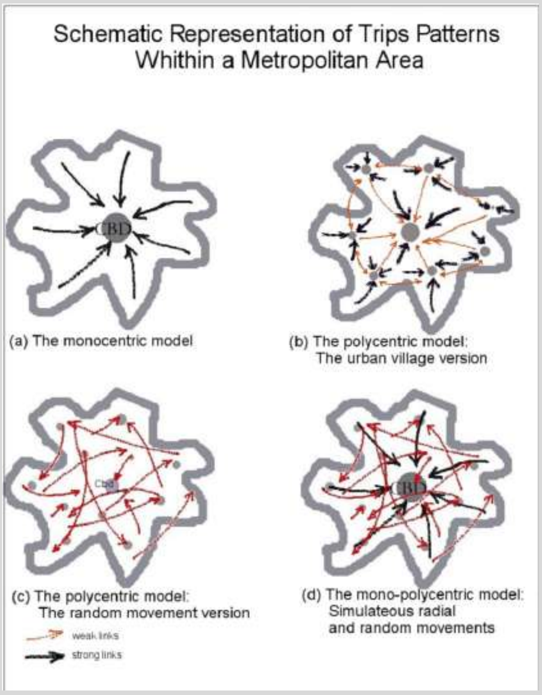


Figure 16: City Models (from Bertaud, 2004)

Urban Village

A theoretical partitioning of a growing city into urban villages to counter geographic dispersal. Urban villages are meant to reduce commuting time significantly, as people only need to commute a short distance from their homes to jobs that are nearby. The Urban Village leads to a fragmented labor market, and is thus undesirable.

No city is ever completely monocentric or polycentric, but they all tend to be somewhere on that scale. Cities start as monocentric, and are often enabled by rail transport in and out of the CBD. They continue to grow towards polycentricity. In both cases all jobs are meant to attract people from all over the city. Trips in polycentric cities tend to be longer than in their monocentric counterparts, as the points of interest are more geographically dispersed. Commuters begin to rely on private vehicles, a very inefficient mode of transportation for commuting. The challenge of effective polycentricity lies in managing an efficient transit network to maintain a unified labor market.
Source: Bertaud, 2004. *The Spatial Organization of Cities*

3.2 Public Transport in Cairo

To get a deeper understanding of public transport, we divide the GCR is divided into four overarching zones, as highlighted in Figure 17. These zones are then divided into 13 unique pairs to get a first understanding of travel pattern using different modes of public transit and ride hailing within the GCR.

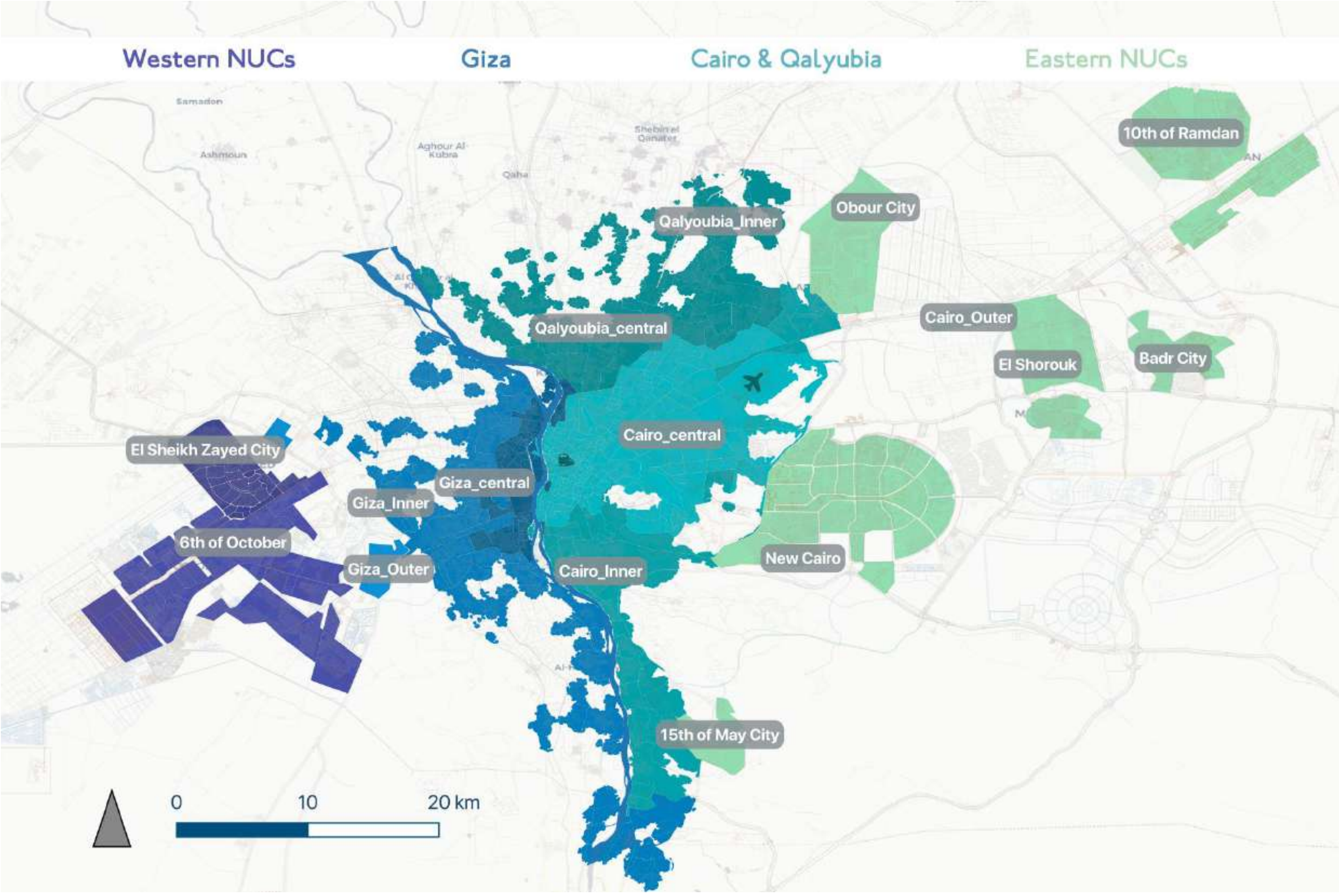


Figure 17: Visualisation of aggregated areas for use as City Pairs within the public transit data analysis

3.1.4. Bus Services

As of 2016, formal bus services operated in the Greater Cairo Region are dominated by the Cairo Transportation Authority (CTA). In the Cairo Governorate, the CTA operates 2650 buses on 427 routes. CTA also began issuing licenses to private operators in 2004. As of 2015, there were sixteen licensed private operators providing service on ninety-nine routes using a total of 1,019 buses. These private buses are mostly twenty-six seater minibuses and so are able to provide service on narrower roads that are inaccessible to the CTA's twelve meter buses (ACE Consulting Engineers and COWI 2016; Cairo Governorate). The minibuses serve the same areas as the regular twelve meter buses, but they have the added benefit of being able to access minor roads.

For both CTA buses and licensed private vehicles, frequency of trips varies across the different routes, with no indication of standard departure times. The average no. of daily trips for CTA buses across all routes is twenty-four, with over 80% of routes having a headway of over thirty minutes. Routes operated by licensed private buses have an average of thirty-one trips per day, which corresponds to less than two trips per hour (ACE Consulting Engineers and COWI 2016).

Data on Bus services (formal and informal) used below has been captured by the consultant over the course of two projects:

- Winter 2017-2018, as part of the Digital Cairo project[5]. Basic route and system adequacy data was collected using mobile devices for 216 unique bus routes covering the western NUC's (El-Sheikh Zayed City, 6th of October City) and the eastern NUC's (New Cairo, El-Obour City, El-Shorouk City and 10th of Ramadan City).
- Summer 2019, as part of a supporting project to this multimodal transport strategy funded by the World Bank. 603 unique bus routes (181 unique CTA routes, 62 unique minibus routes, and 360 unique informal transit routes) covering Giza, Cairo and Qaluibya were collected.

This data was combined and used for the following analysis. It is available in the GIS and GTFS formats. It covers the majority of trips operating within and between the aforementioned geographic areas, and represents a comprehensive geographic coverage.

Table 5 and Appendix I contain statistics on the commercial speed realized, number of unique routes (including directionality) mapped, the average distance travelled, average trip duration recorded during mapping[6], the average fare in EGP[7] and the average fare cost per km of trips.

CTA services and P_O_14 (Informal 14-Seater Microbus) services operating within the Central and Inner Zones of the Greater Cairo Region merit special focus, as together they represent three quarters of the surveyed routes. (See table I1 in the appendix) They are highlighted in light blue. There are almost twice as many informal routes as formal routes. Informal routes tend to be a third shorter, take a third of travel time (i.e. avoid highlight congested routes and operate faster), command the same fares but at double the cost per km (i.e. tickets cost about the same price, but when averaged over distance reveal double the cost per unit of travel).

Table 5 shows the commercial speed realized by the different modes of transport, broken down by origin and destination city pairs. Commercial speed is high for most origin-destination pairs and modes of transport. Traffic congestion affects commercial speed negatively as shown in red. It is particularly

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[5] Digital Cairo was between a partnership Transport for Cairo, Takween for Integrated Community Development (TICD) and Digital Matatus. It was funded by Expo Live 2020 Impact programme.

[6] The Winter 2017-2018 and Summer 2019 mapping exercise should not be seen as representative samples for trip durations, as times of high congestion were avoided during the field research.

[7] Fare data was standardized for Q3 2019: Trips mapped after the July 2019 Price Hike were included as is. CTA routes were modelled based on the published fixed fares sold by the CTA. Informal Transport Routes were either sourced from secondary sources, or modelled using a multiple linear regression model. Details of the updating of the fares are provided in the "Update to GCR Accessibility Analysis (Mapping Central and Inner-Cairo)" report.

slow for services operating within the Central and Inner Zones of the Greater Cairo Region, and further negatively affected by congestion.

Table 5: Average commercial speed of trips represented in the dataset, aggregated by City Pairs. (Values in black are based on data collection, Values in red are high congestion estimations)[8]

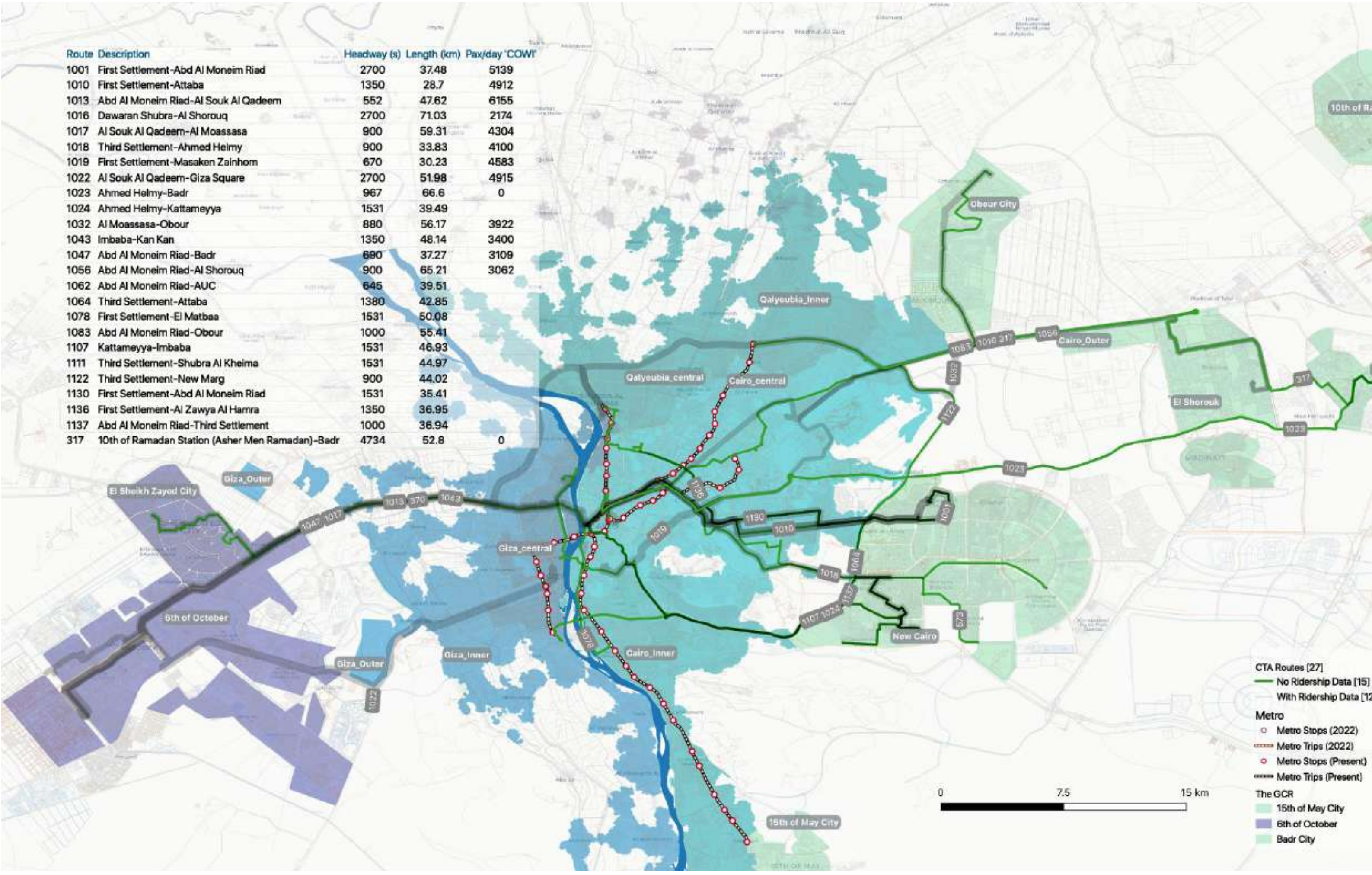
City Pair	COOP		CTA		CTA_M		P_B_8		P_O_14	
	Mapped	Congestion	Mapped	Congestion	Mapped	Congestion	Mapped	Congestion	Mapped	Congestion
Between western NUCs							33 km/h	31 km/h	28 km/h	24 km/h
Cross GCR NUC travel									74 km/h	43 km/h
Cairo & Qalyubia - Eastern NUCs	53 km/h	29 km/h	32 km/h	28 km/h	22 km/h	18 km/h	53 km/h	43 km/h	51 km/h	35 km/h
Eastern NUCs - Cairo & Qalyubia	57 km/h	52 km/h	33 km/h	31 km/h	22 km/h	18 km/h	42 km/h	41 km/h	49 km/h	40 km/h
Cairo & Qalyubia - Western NUCs			33 km/h	29 km/h					56 km/h	30 km/h
Western NUCs - Cairo & Qalyubia	39 km/h	29 km/h	35 km/h	26 km/h					50 km/h	29 km/h
Eastern NUCs - Giza			31 km/h	38 km/h	20 km/h	19 km/h	47 km/h	29 km/h	63 km/h	33 km/h
Giza - Eastern NUCs			48 km/h	53 km/h	23 km/h	15 km/h	66 km/h	36 km/h	58 km/h	48 km/h
Giza - Western NUCs	60 km/h	52 km/h	35 km/h	19 km/h					57 km/h	37 km/h
Western NUCs - Giza	51 km/h	22 km/h	35 km/h	26 km/h					55 km/h	30 km/h
Within GCR Central/Inner	22 km/h	19 km/h	19 km/h	15 km/h	20 km/h	15 km/h	25 km/h	20 km/h	30 km/h	23 km/h
Within NUC							32 km/h	30 km/h	38 km/h	28 km/h

Table I-2 breaks down the unique number of trips operating between City Pairs. The large majority of trips start and end within the geographic areas of Central and Inner Cairo, and are operated by the CTA and informal 14-seater Microbuses. Smaller informal 7-seater microbuses meanwhile dominate service provision within the New Urban Communities, as they're lower capacity is better suited to the dispersed urban fabric and lower demand.

Table I-3 represents average trip durations: Routes designed and licensed by the Cairo Transport Authority tend to be very long in distance (table I-4) and thus also experience long trip durations. A clear difference emerges between the formal and informal sector: the latter, entirely private, is *more efficient by* systematically avoiding congested routes. as evidenced by the relatively higher commercial speeds. It is also more expensive on a per km basis (table I-7), assuming that passengers take the full trip, and constant seat turn-over. The length of the total network is 28,369 km, across all modes and all unique trips. The majority of the total network are formal CTA Buses, closely followed by services provided by informal 14-seater Microbuses. Overlap of segments of routes is highly prevalent.

[8] Codes of the different modes of transport are explained in table D16 in the appendix.

3.1.4.1. CTA Routes connecting the NUCs with Central Cairo



Route	Description	Headway (s)	Length (km)	Pax/day 'COWI'
1001	First Settlement-Abd Al Moneim Riad	2700	37.48	5139
1010	First Settlement-Attaba	1350	28.7	4912
1013	Abd Al Moneim Riad-Al Souk Al Qadeem	552	47.62	6155
1016	Dawaran Shubra-Al Shorouq	2700	71.03	2174
1017	Al Souk Al Qadeem-Al Moassasa	900	59.31	4304
1018	Third Settlement-Ahmed Helmy	900	33.83	4100
1019	First Settlement-Masaken Zainhom	670	30.23	4583
1022	Al Souk Al Qadeem-Giza Square	2700	51.98	4915
1023	Ahmed Helmy-Badr	967	66.6	0
1024	Ahmed Helmy-Kattameyya	1531	39.49	
1032	Al Moassasa-Obour	880	56.17	3922
1043	Imbaba-Kan Kan	1350	48.14	3400
1047	Abd Al Moneim Riad-Badr	690	37.27	3109
1056	Abd Al Moneim Riad-Al Shorouq	900	65.21	3062
1062	Abd Al Moneim Riad-AUC	645	39.51	
1064	Third Settlement-Attaba	1380	42.85	
1078	First Settlement-El Matbaa	1531	50.08	
1083	Abd Al Moneim Riad-Obour	1000	55.41	
1107	Kattameyya-Imbaba	1531	46.93	
1111	Third Settlement-Shubra Al Kheima	1531	44.97	
1122	Third Settlement-New Marg	900	44.02	
1130	First Settlement-Abd Al Moneim Riad	1531	35.41	
1136	First Settlement-Al Zawya Al Hamra	1350	36.95	
1137	Abd Al Moneim Riad-Third Settlement	1000	36.94	
317	10th of Ramadan Station (Asher Men Ramadan)-Badr	4734	52.8	0

Figure 18: Visualisation of Ridership of the CTA routes

Figure 18 shows the formal bus routes operated by the CTA connecting the NUCs with Central Cairo. Out of 25 unique routes, only 13 have ridership data[9]. They are shown in grey, with the width of the visualised line corresponding to daily ridership. Newer routes, which lack data, are visualised in green. Corridor Segments with multiple overlapping routes are darker. The top three used corridors are:

- The Al-Methaq corridor, connecting the third settlement in the New Cairo NUC with Al Khalifa Al Zaher passing by Madinet Nasr contains seven overlapping CTA routes at its midpoint. Only three contain data, and report a combined daily ridership of 14636 passengers. Most of the corridor overlaps with the expected trajectory of the future Line 4 of the Cairo Metro.
- The 26th of July / 15th of May corridor contains five overlapping CTA routes at its midpoint. Only four contain data, and report a combined daily ridership of 13602 passengers.
- The Cairo Ismailia Desert Road corridor contains three overlapping CTA routes at its midpoint. Only two contain data, and report a combined daily ridership of 5236 passengers.

Two corridor segments deserve a special mention:

- The corridor segments connecting Abd-El Moneim Riad with Al Demerdash is the corridor partition most used by different modes of road based public transport in the GCR, and contains eleven overlapping CTA routes at its midpoint. Only five contain data, and report a

[9] Based on COWI CTA Study 2016, which includes route data for 2015 based on reporting by the CTA.

combined daily ridership of 19387 passengers. Most of the corridor overlaps with the existing trajectory of Line 2 of the Cairo Metro.

- The AUC New Cairo - Abbasiya Corridor contains three overlapping CTA routes. However, a 1.6 km segment connecting the Ring Road with the Al Amal street sees the convergence of eleven different CTA routes. Only one contains data, and reports a daily ridership of 4100 passengers.

3.1.4.2. CTA Frequency and Operating Hours

The CTA operates over 400 routes in the GCR, but the network is characterized by many overlaps between the routes as well as low frequencies. A study done by ACE consulting engineers in 2016 found that there were 427 operating routes with 255 different headways (ACE Consulting Engineers and COWI 2016). These routes had an average of twenty four departures per day, equivalent to almost two departures per hour. Over 80% of the routes run with a headway as high as 30 minutes. The study found that there was no correlation between demand for routes (in terms of passengers/hour) and the headway of a route. Not only that, but the number of buses serving a route does not match with its demand.

The limit for running without fixed schedules is usually considered to be a 10 minute headway. Only five CTA routes met this criteria, and yet these were not the highest demand routes, highlighting that there seems to be no discernable pattern when it comes to matching supply with demand.

It is important to note that, while the COWI study is the most recent study done on the CTA, the number of routes reported in it may not be accurate. In the data collection carried out by TfC in the summer of 2019, we found that many of the CTA routes listed online (Cairo Governorate, 2019) had been removed from the ground. We also found duplicates in these reports so some buses were double counted (mainly due to the fact that some bus routes operate with two different numbers simultaneously; an old and a new number). A few routes were found to have only one or two buses operating on them, making them unreliable and unutilized by the public. Other routes run between main hubs in Cairo and villages in the delta. In total, we found 204 CTA routes operating within the GCR with varying headways.

Background Box 7: Cost of Getting from the NUCs to Central Cairo

Service	Fare (EGP)
Sheikh Zayed	
CTA 1047	5
Paratransit	8
6th of October	
CTA 1013	5
Paratransit	8
New Cairo	
CTA 1062	4
CTA 1137	5
CTA 1018 + Metro	8
Shorouq	
CTA 1056	5
Obour	
CTA 1083	5
Paratransit + Metro	NA
Badr	
NA	
10th of Ramadan	
NA	
15th of May	
NA	

Table 6: Cost of getting to Abd El Moneim Riad (A Major Transit Hub in Central Cairo)

To get to Central Cairo using public transport, residents of NUCs have the choice of riding either CTA buses or informal transport. informal transport tends to be quicker and so is preferred by some. CTA buses are more affordable, in part because they have higher capacity and so generate higher absolute revenue per trip.

Table 6 shows the cost of getting from each NUC to Abd El Moneim Riad (A major transit hub in Central Cairo). Residents of the Eastern NUCs have the option of taking the metro once they reach Inner Cairo, helping them avoid congestion. At the moment, residents of Western NUCs do not have this option, as the metro is mostly extends towards the East, North and South.

Even though public transportation in Cairo is among the cheapest in the world (Statista 2018), comparing ticket prices is misleading unless other economic indicators are taken into account. The average public transport ticket price in London is over 15 times that in Cairo, but when the prices are weighed by the minimum wages in the two cities, they are found to be almost the same. This highlights the need for pricing trips based on the purchasing power of the local residents

City	Monthly Minimum Wage (USD)	Daily Minimum Wage (USD)	Bus Ticket Price (USD)	Bus Ticket as % of Minimum Wage
Cairo	68.9	3.445	0.25	7.26%
London	1546.4	77.32	5.66	7.32%
Mexico City	102	5.1	0.29	5.69%

Table 7: Average Ticket Prices ("Cost for Public Transport in Cities Worldwide, 2018 | Statistic") weighed by minimum wage ("Salary Checks -World Wide Wage Comparison - WageIndicator.Org").

3.1.5. Cairo in 2022 - New Infrastructure

3.1.5.1. Overview of New Routes

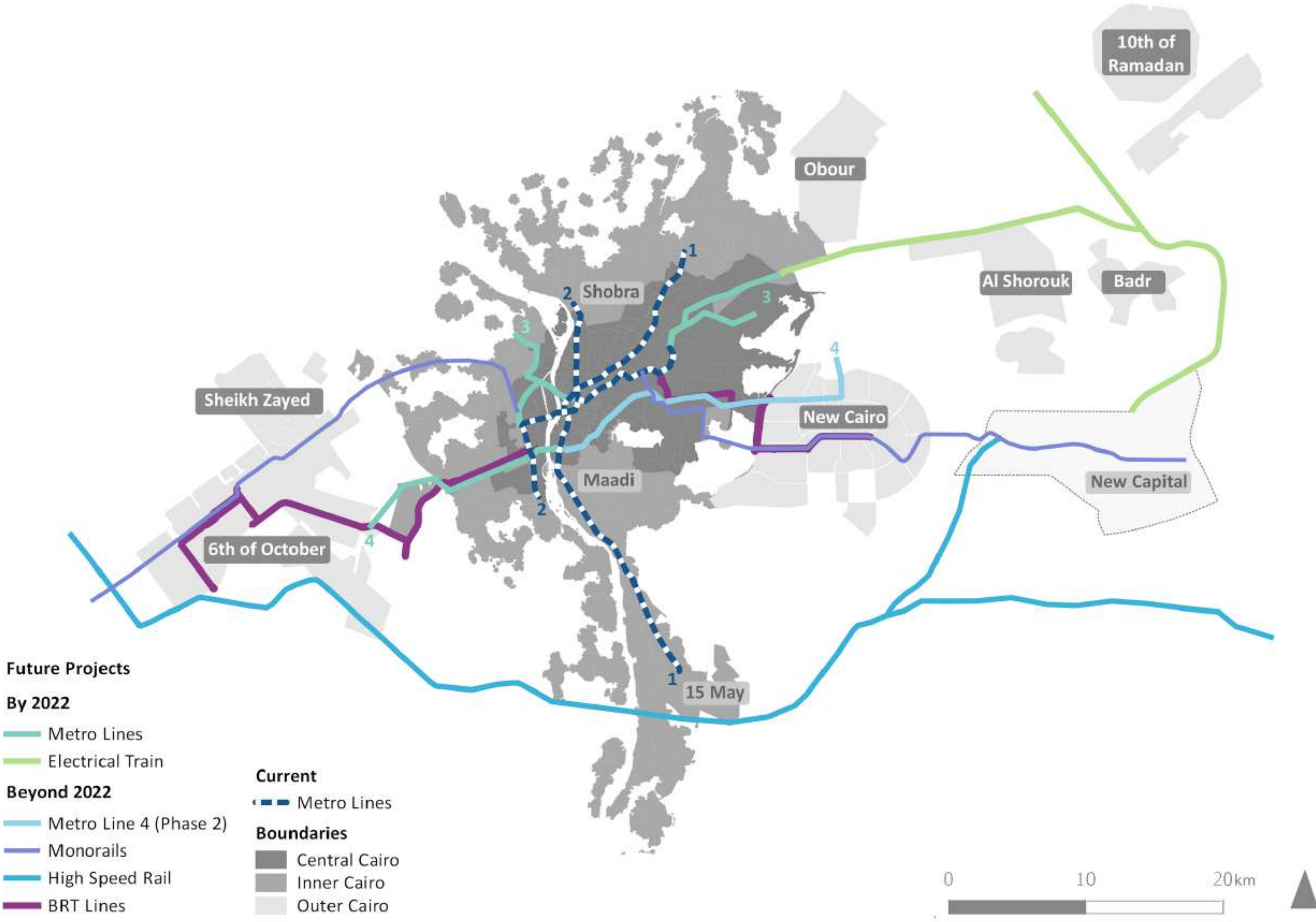


Figure 19: Future rail and BRT infrastructure

Implementation of Line 3 of the Cairo Metro is well underway, with the first two phases already completed. The remaining two phases of line 3 are under construction, with the line expected to be completed by 2023. Work has also begun on the first phase of Line 4 of the metro, which is meant to connect the cities of 6th of October and New Cairo to the metro network.

Line 1 will see an increase in capacity by 40%. An extension of Line 2 from Shubra El Kheima to Qalyub has been recently tendered for a feasibility study .

A Light Rail Train (LRT) will also be built to connect Cairo to the New Administrative Capital. The train, commonly known as the 'Electric Train', will run from the newly proposed Adly Mansour Station at the Eastern periphery of Cairo, passing through Obour, Shorouk and Badr on its way to the New Administrative Capital.

Eight bus routes are in the process of being implemented from Inner City Cairo to the western section of the GCR as part of the BRT Light services to be provided by Mwasalat Misr. These routes will be implemented by Mwasalat Misr who have also begun building bus terminals and park-and-ride facilities in the cities of Sheikh Zayed and 6th of October.

A pre-feasibility study for two high specification BRT corridors was completed by ITDP. The corridors aim to connect Inner City Cairo with the suburbs on either side.

Two monorails on either side of the capital have also been studied. The first will connect the cities of 6th of October and Sheikh Zayed to Giza. The second monorail will be 52 km in length, connecting Nasr City to the New Administrative Capital.

A list of all future projects, including those to be implemented beyond 2022, is detailed in Appendix H.

3.3. Competition to Public Transport in Cairo

3.3.1. Peak-Only Commuter Services

A selection of new peak-only commuter services have eschewed established hubs fully and operate on their own self-determined routes, catering to a more upmarket clientele. They provide direct services with multiple origin-destination pairs, and are thus highly competitive with private cars from a travel time perspective. They tend to operate only a limited number of trips a day, and during limited operating hours, and thus cannot be considered proper public transport. Still, incumbent providers Buseet, launched in 2016, and SWVL, launched just in March 2017 are growing at a remarkable rate.

SWVL already boasts over 100 unique routes, a continuous stream of new investment funding and over 100,000 rides a month. Incumbent ride-hailing services UBER is slowly rolling out its new bus service (UBER, 2018), with multiple routes operating throughout the weekday period. Careem has also launched such a service (Careem Bus 2018), operating multiple unique routes connecting Outer Cairo with Central Cairo.

The consultant believes that these services are likely to play an important part of the transport mix in the NUCs in the near future. As they provide direct services between multiple origin-destination pairs, they are thus likely to prove a competitive threat to mass backbone services from a travel time perspective.

3.3.1.1. Overview of Routes

SWVL and Busset do not publish aggregate data on its route network, making it difficult to assess the extent of its network. A manual check of routes on selected dates[10] sees the SWVL app advertising:

- 6th of October City, El Sheikh Zayed City and New Cairo are connected to the CBD using multiple routes, operating services throughout the day. The Frequency varies throughout the day.
- 15th of May City is connected to the CBD using only one route operating **three downtown-bound trips** in the early morning and the two NUC-bound trips in the evening.
- El Shorouk City is connected to the CBD using only one route operating **five downtown-bound trips** in the early morning and the two NUC-bound trips in the evening. The route further makes a detour to the Al-Rehab residential community.
- El Obour City, 10th of Ramadan City and Badr City are not serviced by any routes.
- The Western NUCs are not connected to each other by any routes.
- The Eastern NUCs are connected to each other by a number of routes linking New Cairo, El Obour City and El Shorouk City with each other.

A similar analysis for Buseet was not possible.

[10] The analysis was conducted for Sunday, 05/05/2019.

3.3.2. Privately organised transport networks

Private sector employers, public sector organizations and schools / universities often organise their employees' or students' transport. This is particularly true in the cases where the organisations premises are situated far from transport corridors, as is the case with Smart Village at the periphery of the Cairo-Alexandria Desert Road; or with new university campuses that are often located in the NUCs. Examples include the AUC, GUC, MSA, 6th of October University, etc. Peak-only commuter service providers such as SWVL and Buseet both operate such services, which remain unpublicized and are in fact allowing employers with much smaller numbers of employees to organise such networks.

These systems affect the development of public transport systems; as transport needs of a big part of employees are already met. Due to the difficulty of data collection, we will not be able to include them within the quantitative analysis to be performed.

Background Box 8: Transport of Government Employees to the New Administrative Capital

At an introductory event to the New Administrative Capital hosted by the Administrative Capital For Urban Development (ACUD) company, officials cited a four-tier strategy to ensure mass transit service provision to and from the New Administrative Capital:

1. The Electric Train (El Salam City - New Administrative Capital);
2. The New Cairo Monorail
3. The organization of private fleets to transport 51,000 public sectors employees to the New Admin Capital, which will be organised by each Ministry for its own contingent
4. The expansion of road networks to link it with the rest of the city

The Electric Train is expected to terminate at 'Mohamed Bin Zayed Axis' station, which lies at the future central business district of the New Administrative Capital. It is planned to be a multimodal transit hub.

Source: Alhusseiny, K. Amin, M, (2019, February)

3.3.3. Ride-hailing Services

Careem, one of the primary service providers of ride hailing services in Egypt, provided the consultant with a statistically significant anonymised sample of its data for the period ranging between January 2017 and May 2018, included. The following sections provide some explanatory analysis of this dataset.

3.3.3.1. Overview of Services

Table 8 highlights aggregates of some basic statistics. To maintain the anonymity of the dataset, the total number of trips was normalised to the lowest city-pair "*Cross GCR NUC travel*". All other city-pairs are then shown as a multiple of that city-pair. The large majority of trips, by a huge margin, are short distance trips starting and ending within the combined area of Central and Inner Cairo, closely followed by trips within the NUCs. Appendix C (7.3.4) contains further analysis.

Short distance trips starting and ending within the combined area of Central and Inner Cairo are the most important segment of trips. Trips within the NUCs come second. Travel between NUCs and the closest Inner and Central GCR areas us markedly less, but still significant.

Table 8: Statistics of Ride-hailing data, provided by Careem. Broken By City Pair.

Averages of trip-level statistics for ride-hailing data.					
City Pair	Trips factor	Avg.distance (km)	Avg.duration (min)	Avg.speed (km/h)	Avg.fare (EGP)
Within GCR Central/Inner	357.0	10.4	26.2	23.8	34.7
Within NUC	82.3	6.9	13.3	31.1	23.5
Eastern NUCs - Cairo & Qalyubia	25.9	23.3	35.3	39.6	63.2
Cairo & Qalyubia - Eastern NUCs	25.0	23.6	34.7	40.8	62.8
Between western NUCs	10.1	11.6	19.4	35.9	33.8
Western NUCs - Giza	9.2	27.5	42.2	39.1	71.3
Giza - Western NUCs	8.8	26.0	37.5	41.6	68.3
Western NUCs - Cairo & Qalyubia	5.4	42.0	62.8	40.1	105.5
Cairo & Qalyubia - Western NUCs	4.9	40.7	58.4	41.8	102.5
Eastern NUCs - Giza	2.8	37.8	57.8	39.2	97.1
Between eastern NUCs	2.7	25.6	30.2	50.9	65.4
Giza - Eastern NUCs	2.7	39.3	56.0	42.1	98.5
Cross GCR NUC travel	1.0	62.4	72.4	51.7	143.9

3.3.3.2. Distribution of trips

An interesting pattern occurs: All city-pairs exhibit similar behaviour, with the majority of trips occurring within working hours. Ride-hailing usage peaks during the 3pm-6pm timeframe, closely followed by the 6pm-9pm timeframe.

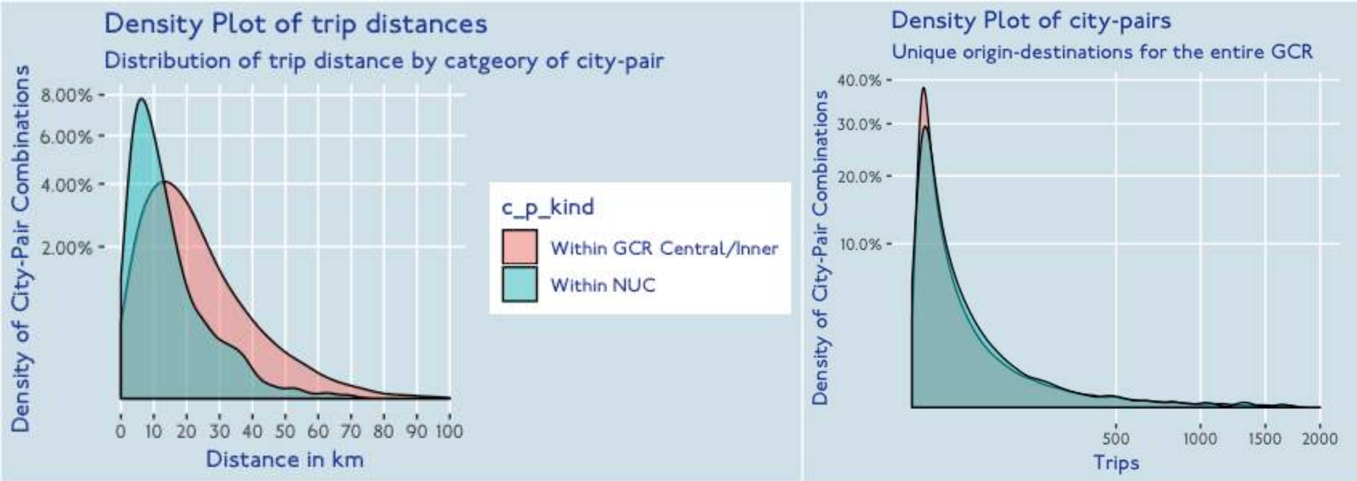


Figure 20: (Left) Density Distribution of trip distances in the Ride-Hailing data.

(Right) Density Distribution of number of trips by unique combination of city-pairs for the entire GCR. The y-axis corresponds to the frequency in decimal of trips within the entire dataset.

Computing the distribution of distances yields a more even poisson distribution, with a dataset mean of 12.7 km and a median of 9.03 km. 26.8% of trips are less than 5km. Most ride-hailing trips across the GCR are therefore long distance trips. (Figure 20 (Left))

Comparing trip distances within NUCs [mean = 6.90 km & median = 5.51 km] with trips within inner / central Cairo [mean = 10.4 km & median = 7.91 km] reveals a more powerful difference.

3.3.3.3. Most common Origin-Destination pairs

We then aim to identify the most common combinations of trips taken using ride hailing services. To do so, we assign the pick-up and drop-off points to the hexagonal grid system used within the study. Each Hexagon has a radius of approximately 550m; yielding an area of 0.88km^2. Then, all possible combinations of trips across the metropolitan area are examined: 324,691 unique combinations. Each combination corresponds to a trip starting at area x and ending at area y. Trips connecting the return trip y-x are counted separately.

Computing the density distribution of these origin-destination pairs yields a poisson distribution; a naturally occuring distribution. (Figure 20 (Right)) 75% of the combinations account for 74.06% of all trips. This indicates that the large majority of trips taken using ride-hailing services occur between combinations of city-pairs that are seldom travelled; most likely less than once a day. This makes intuitive sense: travellers are more likely to choose relatively expensive ride-hailing services for trips that start or end at unusual areas (due to the flexibility of the ride-hailing technology) and for direct travel to areas that are not serviced by mass transit.

Comparing density distribution of origin-destination pairs within NUCs with trips within inner / central Cairo shows trips to be more concentrated within the NUCs. This conclusion is all the more powerful given the bigger area distances experienced within the NUCs, and can be interpreted as follows: Travel patterns are more concentrated within the NUCs, and there is thus room to aggregate individual ride-hail trips.

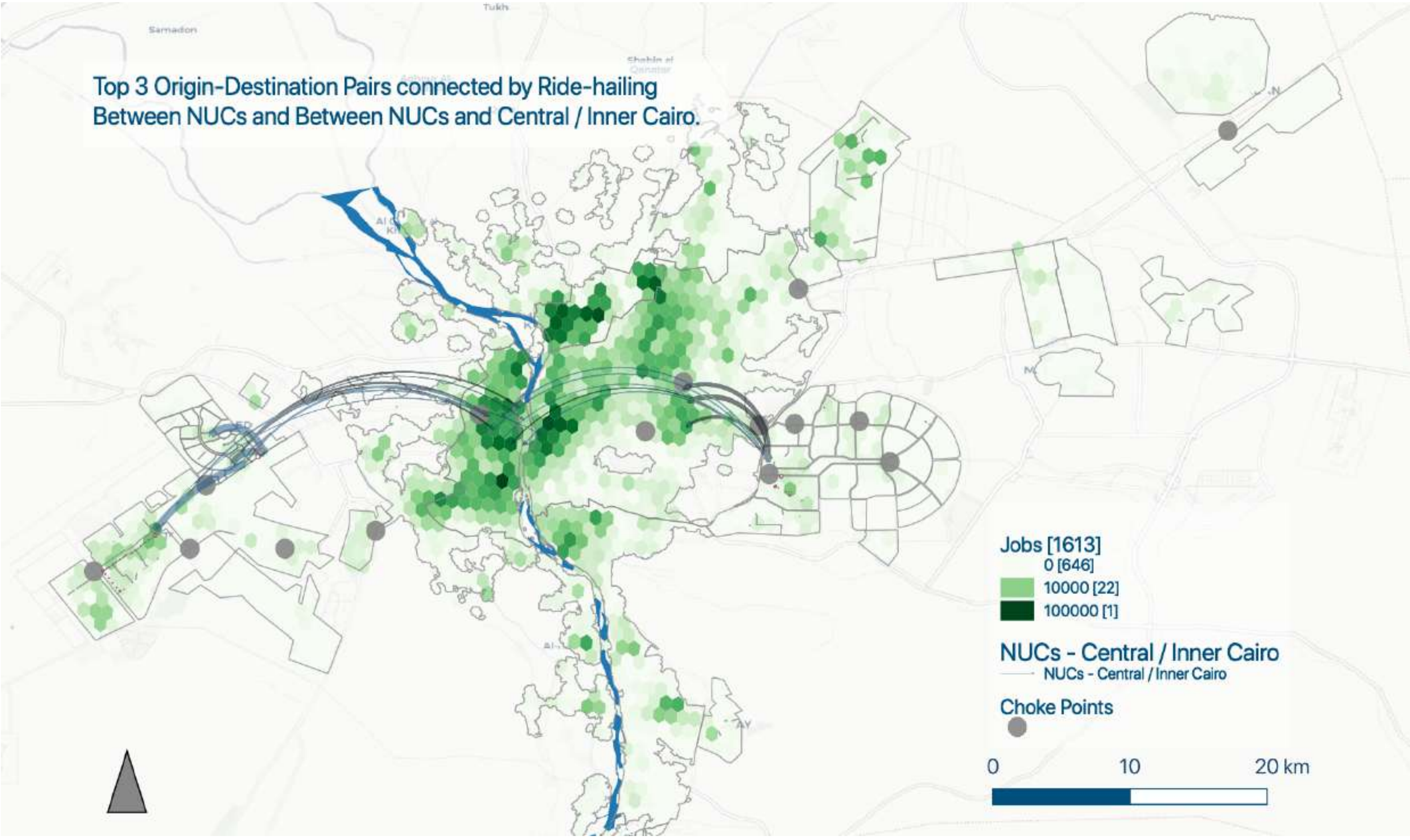


Figure 21. Origin Destination pairs connected by ride-hailing within NUCs and between NUCs and Central and Inner GCR.

Figures 21 visualises the most common itineraries across the GCR. It shows the most common origin destination city pairs for trips that connect the NUCs with Central and Inner Cairo. The width of the lines indicate the relative frequency that this origin destination combination is travelled. Dark blue lines indicate single direction; black lines indicate that this particular origin destination city pairs is travelled often in both directions. Choke points shown in these maps are the same as those defined in section 2.4.2.

Some clear patterns emerge: The most common trips by a large margin are trips connecting New Cairo, particularly Cairo Festival City, with Nasr City, along the entire direction of Makram Ebeid boulevard. Mohandessin, the district with the second highest density of employment opportunities after downtown, receives the second biggest portion of trips from the eastern NUCs, and most traffic from the western NUC's.

Figure 22. Top Origin Destination pairs connected by Ride-hailing in the Western NUCs 6th of October and El-Sheikh Zayed

Figure 22 zooms in on the western NUCs (6th of October and El-Sheikh Zayed Cities), and visualise travel starting and ending within each respective NUC (Orange) and travel connecting the two NUCs with each other (orange). The three most common unique origin-destination pairs for each city-pair all cluster around the major transit hubs of Al-Hossary (6th of October) and Hyper One (El-Sheikh Zayed City), which also happen to be the areas with the highest density of estimated job opportunities within each respective NUC.

For the eastern NUCs, travel patterns within all NUCs except New Cairo are quite weak; and should not be overinterpreted. Travel within New Cairo is highly centralized around the remote eastern side; and away from the dense internal transit network found in the western side of New Cairo.

3.3.3.4. Application of Ride-hailing insights to the Study

The ride-hailing analysis is a rare dataset that reveals demand for travel in the GCR. Although it is limited to those residents who can afford using the services, it can give some insight on the preferences of a portion of the population on the areas and times that are common for urban travel. In our recommendations for the locations of Park and Ride facilities, the ride-hailing data will act as a proxy to those riders that are likely to convert to a transit mode if given the option.

The distribution of ride-hailing trips corresponds to the polycentric model 'random movement version' proposed by Bertaud, as described in Background Box 6.

3.3.4. White Cabs, Three-wheelers and Two-wheelers

White Cabs provide the main form of traditional taxi services with the GCR. While they have lately come under competitive pressure from the emerging ride-hailing services; they still do provide extensive service within Inner and Central Cairo and are understood by some as a form of public transport. Little data, and no geographic tracing, of their services exist.

Three wheeler vehicles, locally known as Tok-Toks, provide taxi-like services within particular geographic zones; particularly at the urban periphery of Central and Inner Cairo in high density areas; and within some of the NUCs. Services tend to be last-mile services connecting transit hubs at the periphery of residential housing.

Two-wheeler moto-taxis, common in sub-saharan Africa, are a rarity in Egypt. They can be found at the periphery of the metropolitan areas. Recently, ride hailing companies, particularly Uber, started marketing moto-taxi services as a higher-speed lower cost alternative to hailing a car within the GCR.

None of these three taxi-like services qualifies as public transport. However, their role and contribution within the urban transport system should not be underestimated. More data on such services should be collected and used to determine future transport interventions within the GCR, particularly their role within multimodal trips starting and ending within Inner and Central Cairo.

3.4. Travel in Cairo

3.4.1. Traffic Congestion

The GCR suffers from chronic traffic congestion. Traffic loads are very high, and transportation needs are increasing. Figure 23 visualises the average speeds across the metropolis, based on the data collection on travel time.

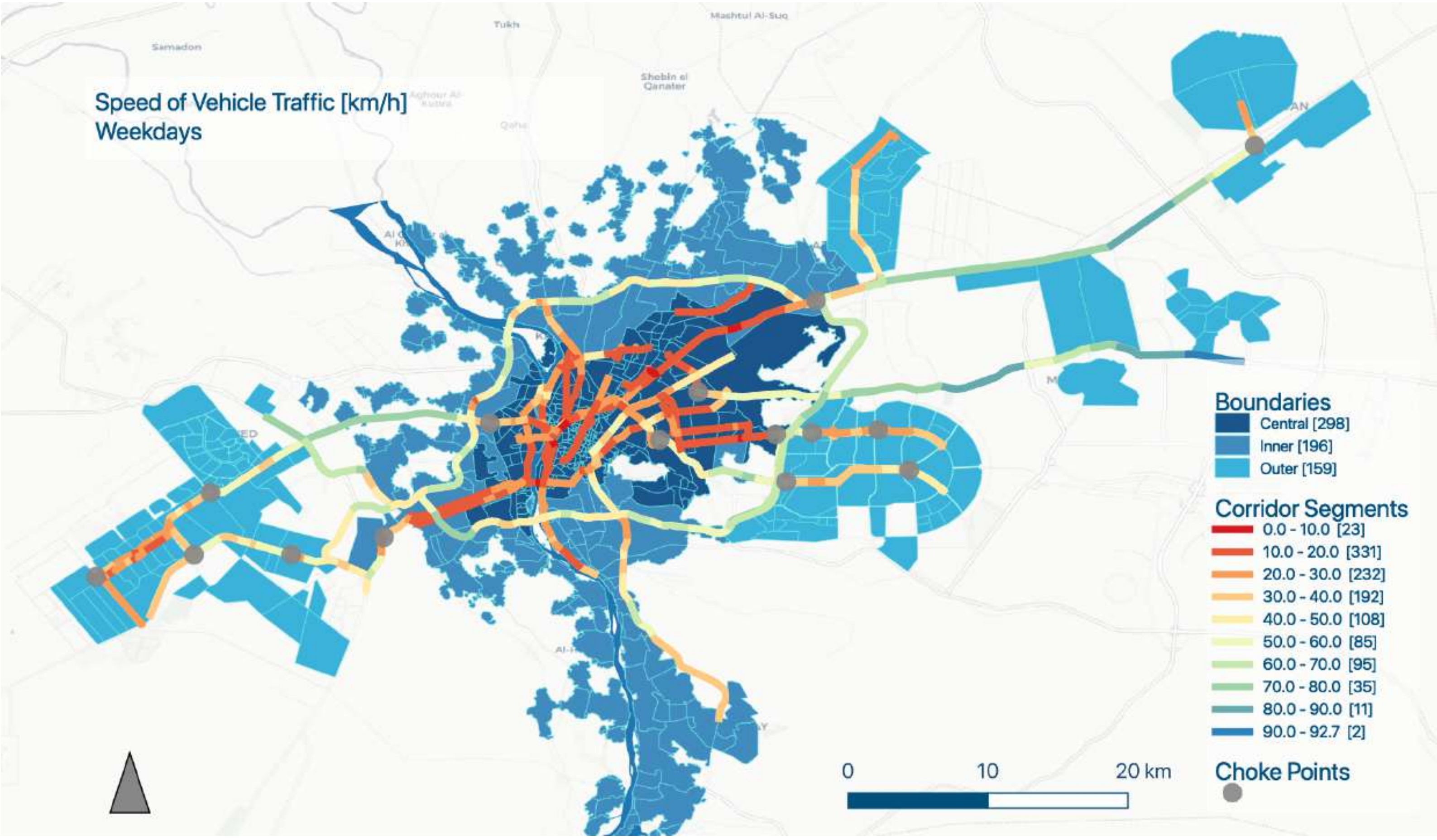


Figure 23: Visualisation of Speed of vehicle traffic [km/h] across the GCR, for weekdays. It shows a pattern of generalized congestion within Central Cairo. The ring road and corridors connecting Inner Cairo with Outer Cairo generally provide better average flow of traffic. However, all corridors experience slowdowns once they reach NUCs.

Understanding network congestion, its implications on the GCR as a whole, and deriving actionable recommendations on the corridors most suited for intervention requires a detailed analysis at different scales of geography and time. In particular, we need to look at the level of each corridor, and each segment, to identify choke points or congestion hotspots.

It is important to remember that everybody suffers from traffic congestion: Pedestrians; Motorists; Public Transport Users and Private Transit users. Congestion should therefore give rise to priority treatment to favor public transport as it carries the highest number of passengers per unit space.

3.4.2. Roles of Public Transport

To understand bus services within public transport, we have to identify what exactly the service offered will look like. In general, there are three different types of services that buses can operate. The difference between them lies in differing stop patterns and frequency of operation.

1) **Local Service**: These are characterized by closely spaced stops (<400m). The buses stop often and so they are naturally quite slow. Such services are ideal for connecting people from their homes to nearby transit hubs, but not for long journeys.
2) **Rapid Service**: Stops are more spaced out for rapid services, allowing for faster commuting times. These services are meant to link nodes of activity, and are not meant to be available at every point on the route. The efficiency and high frequency of the service makes them worth walking the extra distance to get to.
3) **Express Service**: These operate on routes with stops limited to the beginning and end segments. Large non-stop segments mean that they get people to their destination in an efficient manner. Such a service is ideal when there is low population and employment density between the points of interest.

The nature of the GCR means that services connecting the NUCs with Inner and Central Cairo are either Rapid or Express. The choice of which is dependant on the characteristics of the itinerary of the corridor. Looking at the western NUCs, it is clear that the two corridors linking them to Inner Cairo pass through areas of different characteristics and so will naturally require different kinds of services. CAI_SO_1 (26th of July / 15th of May corridor) connects the Industrial Zone in the 6th of October City with Downtown Cairo. While there will be demand along the corridor at both ends, the 26th of July corridor passes through agricultural land with very low residential density. An express service linking the NUCs with the Mohandessin, Zamalek and downtown centers of employment is therefore ideal for such a corridor.

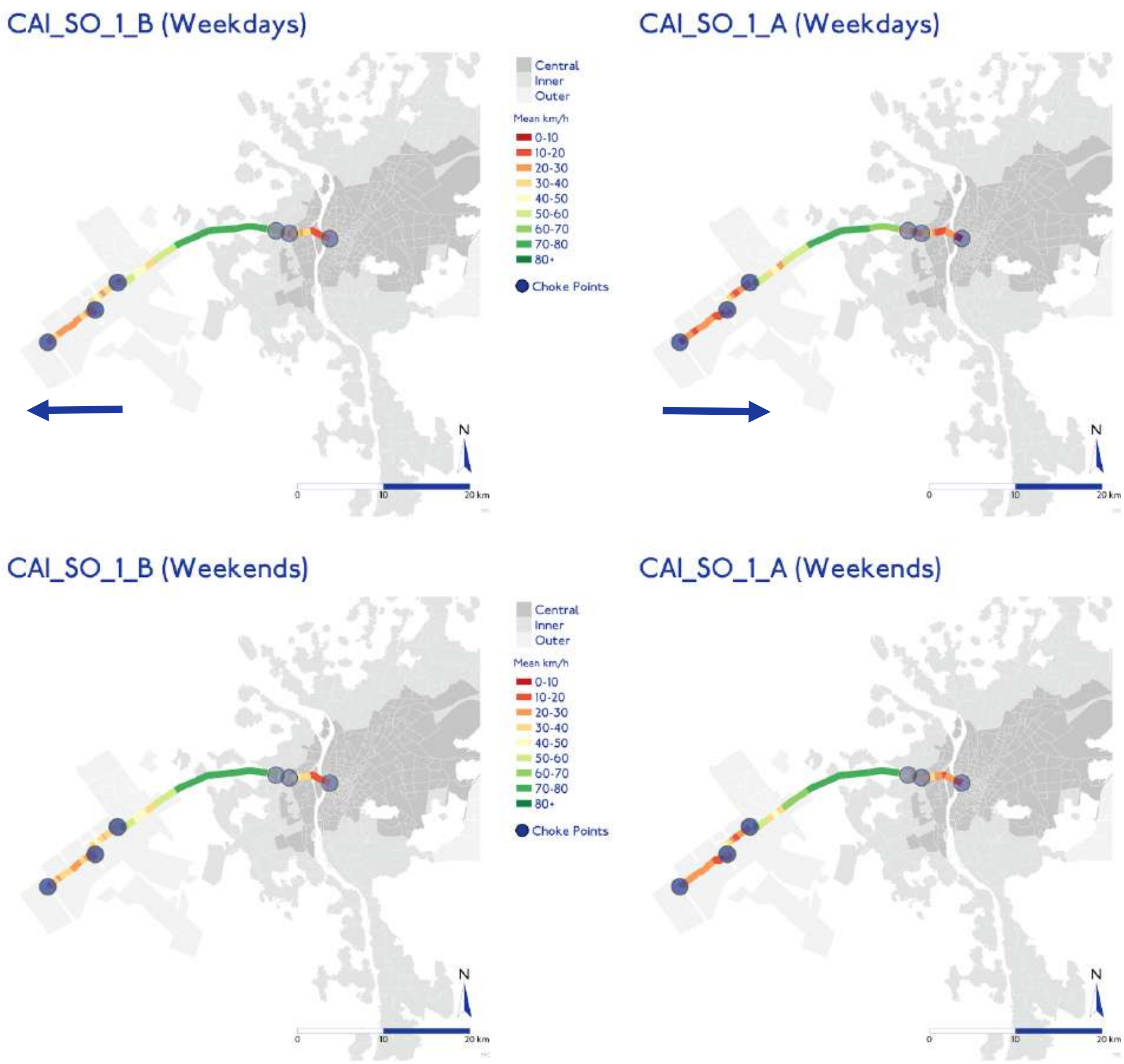


Figure 24: Speed of vehicle traffic [km/h] & Choke Points across CAI_SO_1 (26th of July / 15th of May)

CAI_SO_2 (Wahat-Remaya-Faisal corridor) on the other hand, passes through areas with different characteristics. It passes along the border of Hadayek El Ahram, an area with a high residential density over 30,000 people/km², and then through Faisal Street, an even denser area. Any service passing through all likely to stop all along the corridor.

Hence, the *6th of October to Inner City Cairo* high specification BRT corridor currently proposed by the ITDP is best understood as a local service connecting the large populations lying within its catchments areas to 6th of October on the west; and to Giza Square on the east. Long-range travel from 6th of October to Giza square, as envisioned by the *D-Direct* BRT lite service to be implemented by Mwasalat Misr, UNDP and NUCA is unlikely to provide attractive total trip times.

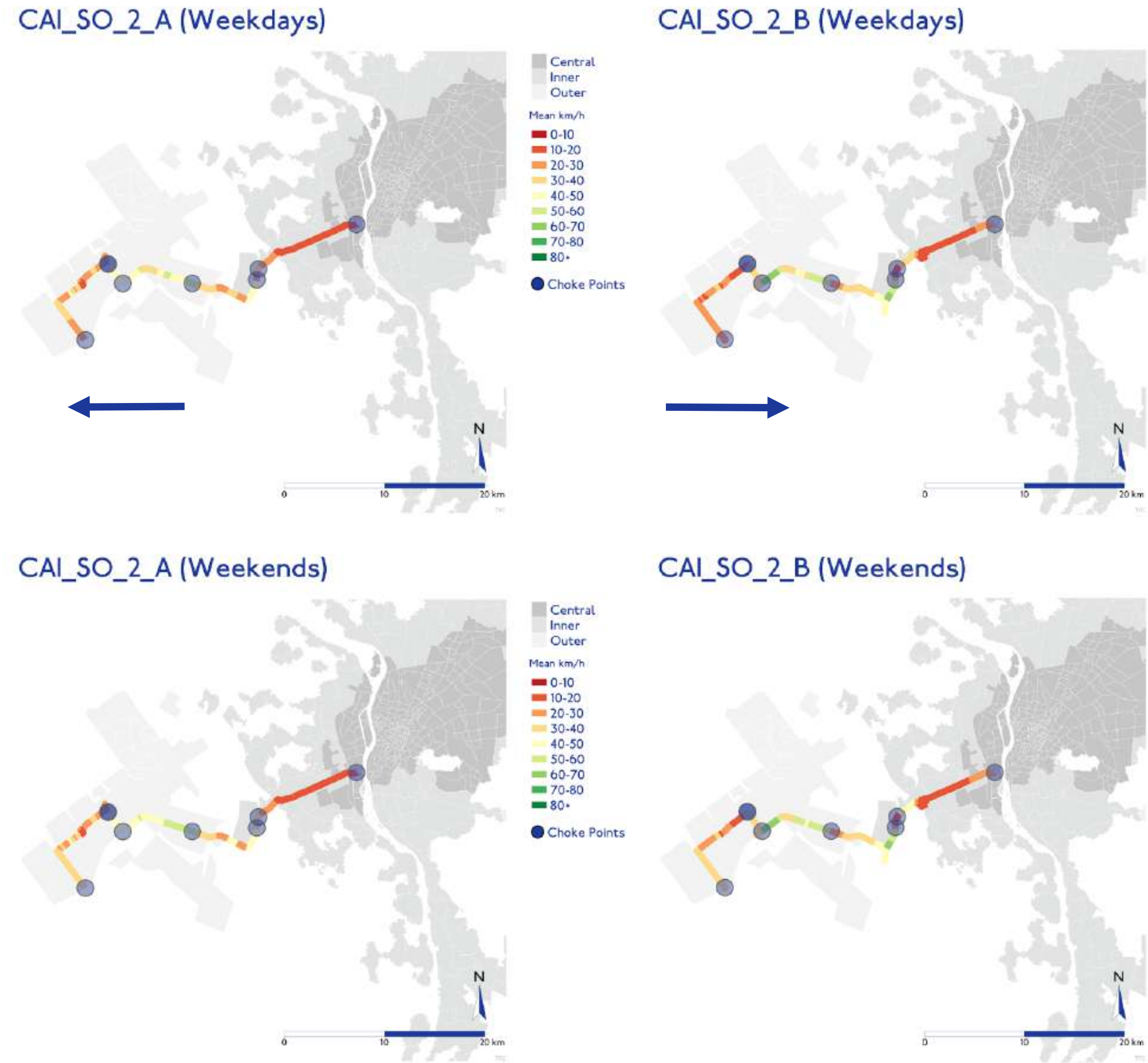


Figure 25: Speed of vehicle traffic [km/h] & Choke Points across CAI_SO_2 (Wahat-Remaya-Faisal)

4. Analysis and Recommendations

In this section, we use our automated method to compute the single point accessibility analysis and replicate it for each area unit used in our analysis, i.e. hexagon. The centroid of each area unit will be used to capture the weighted opportunities reachable to it.

This metropolitan accessibility analysis will be computed for the present situation using GTFS feeds that depict the 2019 public transport network in the NUCs and the GCR. It will then be performed for future potential scenarios; computing the resulting accessibility improvement of each scenario.

This process will be repeated for each corridor in our study. The improvement of accessibility is measured separately for each scenario. Moreover, we will compute a final future scenario that incorporates transportation projects expected to be completed in a 15 year horizon as well as the recommended corridors of this study.

4.1. Present Accessibility Situation

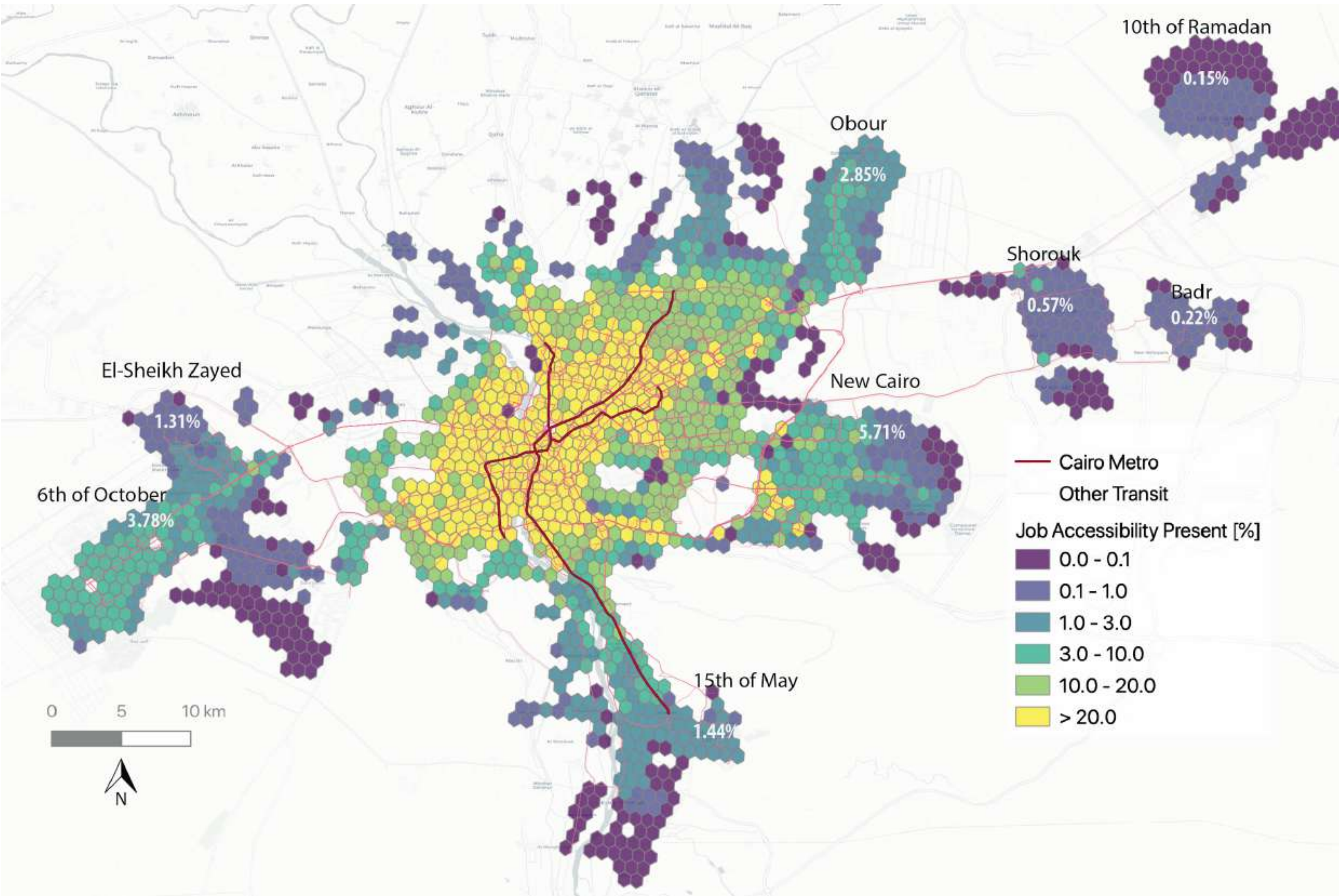


Figure 26. Map of the job accessibility indicators of different parts of Cairo in the Present 2019 Scenario. NUC weighted regional averages are written in white over the NUC area. Data Source: Author's datasets of GTFS and Opportunities

Figure 26 shows the hexagons colored according to the accessibility score of each area: The percent of jobs in the GCR that are reachable by public transit within 1 hour using the present 2019 network. It shows, unsurprisingly, that the best access to jobs occurs in central Cairo. According to our Spatial Employment Model, most jobs are located there. The NUCs have very low levels of regional accessibility indicators with an average of about 2% and a maximum of 6.7% in New Cairo.

Upon closer inspection, the Cairo Metro appears to be the main public transit driver of the high accessibility that is found in the central parts of the city. Areas that are 500 m or more away from the closest public transport route have been excluded from the Analysis. They are represented as greyed out hexagons.

The Regional Access scores - shown in white colour in Figure 26 - show the percentage of GCR jobs reachable within 1 hour of public transport from the NUCs. It shows that the average scores for the NUCs are quite low, especially compared to the Inner and Central zones of Cairo and Giza. These score about 23% accessibility (Not shown).

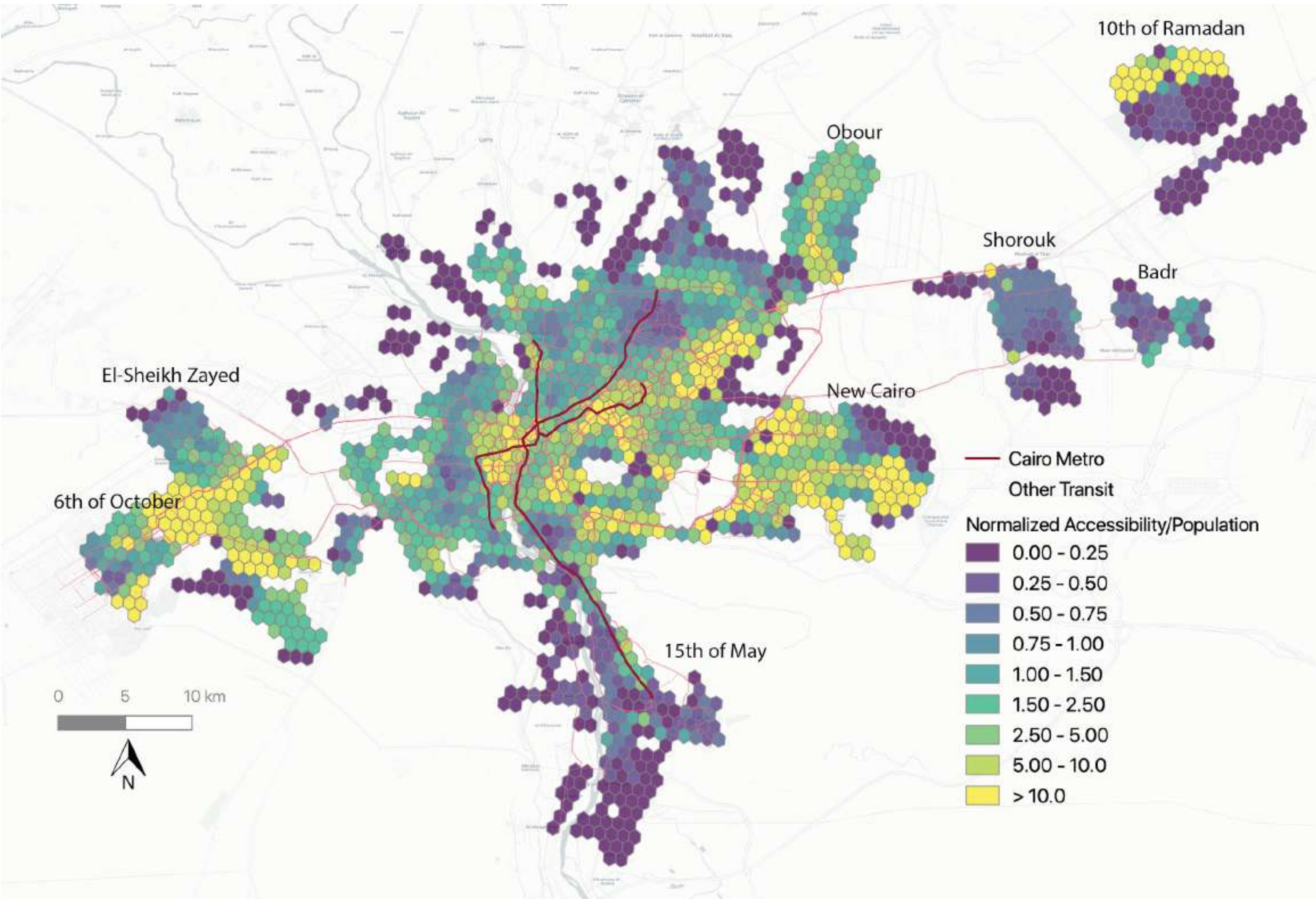
We can expect a low regional accessibility score for the NUCs for a couple of reasons. First, as we saw in the Spatial Employment Model, most jobs are located in the central and inner parts of the GCR. Without much effort, residents of these areas are able to reach a much larger portion of jobs. Another major factor is the Cairo Metro, which does not operate in the outer zones (i.e. the NUCs) and contributes greatly to frequent and speedy transportation of commuters to jobs.

The weighted average metropolitan accessibility measure of the present scenario is around **17.59%.** However, this mean is not distributed evenly with some parts of the city achieving much higher relative accessibility than other more populated parts.

4.1.1. Demand Gaps

In Figure 27, the values of population density and accessibility are compared in each hexagon by computing a ratio of normalized values of present accessibility to population. The normalization was done by dividing each hexagon's value of accessibility by the maximum in the data set. The same was applied to population. Figure 27 shows hexagons of yellow hue to be high in population but low in access; purple hue are high in access but low in population; finally, the hexagons with high green hue have a balanced proportion of both. It is not surprising to see that the green parts are found in Inner Cairo, especially near Shobra el Kheima and Downtown Cairo as well as in inner parts of Giza. NUCs generally have low accessibility. When this low accessibility is combined with even lower population we see purple hexagons (in the centers of 6th of October and New Cairo); When it is combined with high population it results in yellow hexagons (outskirts of some NUCs, all of other NUCs). Hexagons in grey are outside the 500 m buffer around the Inner city public transport data used in the model.

Figure 27. Map of the Ratio of normalized accessibility with normalized population density. Hexagons with low job access relative to population are colored in shades of purple; a balanced accessibility to



population are colored in shades of blue-green; higher accessibility to population are colored in yellow.

Choosing vs. building gender sensitive corridors

The Accessibility Analysis performed in this study is gender-neutral. This does not adequately take into account differences in real-life accessibility experienced between men and women. The resulting selection of corridors is a strategic proposition. Future work on the *Service Planning and Policy Formulation* and the *Project Design and Operational Policies* dimensions is required to be gender-sensitive, tailoring the implementation of PPTI's on the corridors to women's specific needs. Only then can equitable accessibility between genders be assured.

4.1.2. Equity Considerations

A key objective of this study is to determine transit solutions for residents in an equitable manner. Martens (2017) asserts that improvements to accessibility, which are themselves a better gauge than improvements in mobility, such as speed, should be targeted to areas with low accessibility over those with already high accessibility.

This is operationalized in our study by ensuring that the NUCs on the eastern as well as western ends of the city are reached by our recommendations since NUCs have a low accessibility to central GCR opportunities. Moreover, the current transit situation already ensures that the middle to lower income neighborhoods of the city are well connected since they are concentrated in the inner and central parts of Cairo, Giza and especially Qalyubia. The neighborhoods around the Ring Road, especially in the once rural villages in Qalyubia in the north of the GCR are high density informal settlements bisected by the Ring Road. These socio-economic considerations are combined with the quantitative accessibility assessment to provide a balanced recommendation.

4.2. 3 Key-Demand Corridors for future PPTI interventions

Our spatial employment model shows that the majority of jobs are located in Central Cairo. For any PPTI to substantially improve accessibility, it must provide access to this area. The PPTIs analyzed are the ones shown in Figure 28. Each corridor is given a scenario letter for ease of identification in the subsequent results tables. Scenarios letters are shown in table 9.

The commercial speed assumed for PPTIs is 35 km/h. This is based on BRTs that run local routes and is only suitable for segments inside Inner and Central Cairo where the PPTI would indeed act as a local service. The commercial speeds on segments that connected the NUCs with Inner Cairo was derived from actual travel speed data along those highways. If a highway had an average speed - according to our travel time dataset - higher than 35 km/h, that higher speed was assumed. Otherwise, the minimum speed of 35 km/h was taken since the PPTIs are assumed to have bus right-of-way infrastructure.

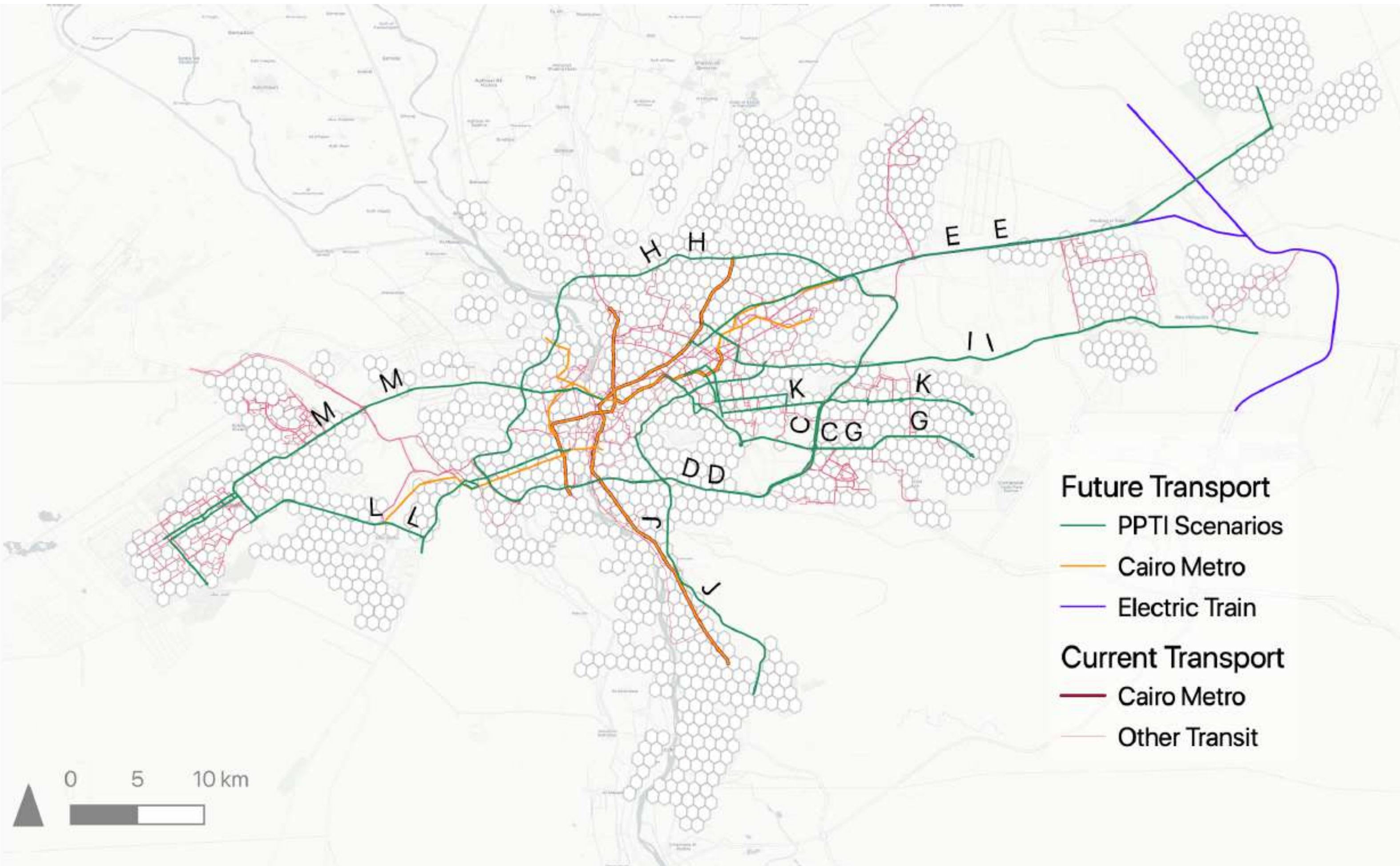


Figure 28. Map of Study Area with PPTI Scenarios and All other Transit.

Table 9: Corridors analyzed, and associated Code Letter.

Code	Description	Main Highway
A	Present	
B	Future Medium Term Horizon (Base Scenario)	All future infrastructure live by 2022 (No PPTI)
C	Future Medium Term Horizon (single PPTI)	Youssef Abbas - AUC
D	Future Medium Term Horizon (single PPTI)	Ring Road - South
E	Future Medium Term Horizon (single PPTI)	10th of Ramadan City - El Qubba Bridge
G	Future Medium Term Horizon (single PPTI)	AUC Campus - Abbasiya Square
H	Future Medium Term Horizon (single PPTI)	Ring Road - North
I	Future Medium Term Horizon (single PPTI)	Badr City - Ibn El Hakam Square
J	Future Medium Term Horizon (single PPTI)	Kilo 4.5 Bridge - 15th of May City
K	Future Medium Term Horizon (single PPTI)	Al Khalifa Al Zaher - Lotus
L	Future Medium Term Horizon (single PPTI)	Giza Square - Industrial Zone
M	Future Medium Term Horizon (single PPTI)	Industrial Zone - El Esaaf

4.2.1. Results of Analysis by Corridor

The results of the accessibility analysis under the assumptions detailed in the Appendix are presented for each corridor scenario in Table 10 and 11.

- Scenario A corresponds to the present.
- Scenario B corresponds to the baseline future scenario with only external projects and none of our PPTIs.
- Scenarios C to M correspond each to one of the PPTI corridors.

Therefore, we compare every PPTI scenario (C to M) with Scenario B to decide which is the most beneficial to the residents of the city. The cells are colored in shades of green that indicate a scale of improvement over baseline Scenario B, each Region or NUC's scale is made independently.

Table 10. Accessibility Analysis Results of Single Corridor Scenarios on NUCs (Base Scenario in Bold)

City	A	B	C	D	E	G	H	I	J	K	L	M
10th of Ramadan	0.15	**0.15**	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
15th of May City	1.44	**1.49**	1.49	1.49	1.49	1.49	1.49	1.49	1.66	1.49	1.49	1.49
6th of October	3.78	**3.86**	3.86	3.86	3.86	3.86	3.86	3.86	3.86	3.86	3.94	4.05
Badr City	0.22	**0.22**	0.22	0.22	0.22	0.22	0.22	0.25	0.22	0.22	0.22	0.22
El Sheikh Zayed City	1.31	**1.79**	1.79	1.79	1.79	1.79	1.79	1.79	1.79	1.79	1.79	2.20
El Shorouk	0.57	**0.57**	0.57	0.57	0.58	0.57	0.57	0.58	0.57	0.57	0.57	0.57
New Cairo	5.71	**5.87**	6.25	6.73	5.88	5.87	5.92	5.89	5.88	6.36	5.88	5.87
Obour City	2.85	**3.11**	3.11	3.11	3.21	3.11	3.11	3.11	3.11	3.11	3.11	3.11
Metropolitan	17.59	**24.49**	24.66	24.62	24.60	24.49	26.31	24.53	24.62	24.57	24.56	24.80

Table 11. Accessibility Analysis Results of Single Corridor Scenarios on non-NUC zones of the GCR (Base Scenario in Bold)

City	A	B	C	D	E	G	H	I	J	K	L	M
Cairo_Inner	10.68	**18.58**	18.60	18.76	18.62	18.58	18.68	18.58	19.01	18.58	18.63	18.58
Cairo_Outer	0.10	**0.51**	0.51	0.51	0.70	0.51	0.51	0.51	0.51	0.51	0.51	0.51
Cairo_central	24.43	**33.54**	34.00	33.55	33.84	33.54	33.78	33.64	33.77	33.73	33.54	33.54
Giza_Inner	9.21	**12.19**	12.19	12.34	12.19	12.19	15.13	12.19	12.19	12.19	12.35	13.37
Giza_Outer	4.53	**13.24**	13.24	13.26	13.24	13.24	13.51	13.24	13.24	13.24	14.76	13.24
Giza_central	25.50	**35.15**	35.15	35.53	35.15	35.15	38.81	35.15	35.15	35.15	35.28	35.94
Qalyoubia_Inner	5.75	**7.85**	7.85	7.85	7.85	7.85	11.45	7.85	7.85	7.85	7.85	7.85
Qalyoubia_central	20.57	**27.58**	27.58	27.58	27.58	27.58	31.99	27.61	27.58	27.58	27.58	27.58
Metropolitan	17.59	**24.49**	24.66	24.62	24.60	24.49	26.31	24.53	24.62	24.57	24.56	24.80

The highest improvement on the metropolitan level comes from scenario H (Ring Road - North), which is entirely due to improvement in the inner and central parts of all three governorates that make up the GCR. Scenario H corridor corresponds to the northern portion of the Ring Road highway. A PPTI on this corridor would ensure a bus or light rail system that is separated from traffic.

A quick glance at the improvement neighborhoods of each scenario verifies the veracity of our method. For example, scenarios C, G and K and to a lesser extent I and D all pass near New Cairo and we can see that its accessibility improves in their scenarios. Similarly, scenarios L and M pass through or near the western suburbs of 6^{th} of October and El-Sheikh Zayed and all the zones of Giza which they go through.

Some corridors have less of a positive effect on accessibility than others.

- For example, scenarios E, I and K increase the metropolitan average only very slightly. This can be due to several factors that are common to these scenarios.
- Scenario E (10th of Ramadan City - El Qubba Bridge) runs along the same corridor as the Future Electric Train project so any gains to Badr and 10^{th} of Ramadan were realized in the base scenario B and the PPTI in scenario E has little added value.
- In scenario K (Al Khalifa Al Zaher - Lotus), the same route is heavily covered by existing formal bus and informal transport routes and travel speeds are high, so the access is already realized.
- In scenario I (Badr City - Ibn El Hakam Square), we suspect the sheer distance from the center of the city where most opportunities are found is already far and one hour is not sufficient to cover the distance. It also only passes along the outside of the NUCs Shorouk and Badr, which limits its ability to reach the residents.

4.2.2. Combinations of PPTIs

4.2.2.1. Accessibility Analysis results for 2 corridor combinations

The combinations of the highest achieving single corridors are combined together to realize improvements in several areas at once and in the overall metropolitan average. The results of these model runs, split by NUC or GCR zones are shown in Tables C7 and C8 in Appendix C.

- Scenario H (Ring Road - North) was combined with the top six other corridors.
- Scenario M (Industrial Zone - El Esaaf), the second in rank, was combined with a couple of scenarios on the opposite side of the city. The combinations with scenario C (Youssef Abbas - AUC) improve every non-NUC GCR zone as shown in Table C8 in Appendix C. However, overall improvements from the combinations with scenario M are less beneficial. Details of the results for double Corridor analysis are in Appendix C.

Moreover, the ride-hailing data analysis has shown the highest OD pairs connecting NUCs with central and inner Cairo to be between 6th of October NUC - inner Cairo as well as New Cairo NUC - inner Cairo. If we can assume that these ride-hailing results are proxies for general travel demand, then our choice of corridors M and C serve an additional purpose of responding to the highest demand for travel across the GCR. Their implementation may lead to a decrease in ride-hailing trips in favor of the same trip by PPTI.

4.2.2.2. Accessibility Analysis results for 3 corridor combinations

To achieve the highest accessibility overall and to ensure that both eastern and western parts of the GCR are being served by our recommendations, we combine the best double with a third corridor and run the model with 3 corridors. The results are shown in Tables C9 and C10 in Appendix C.

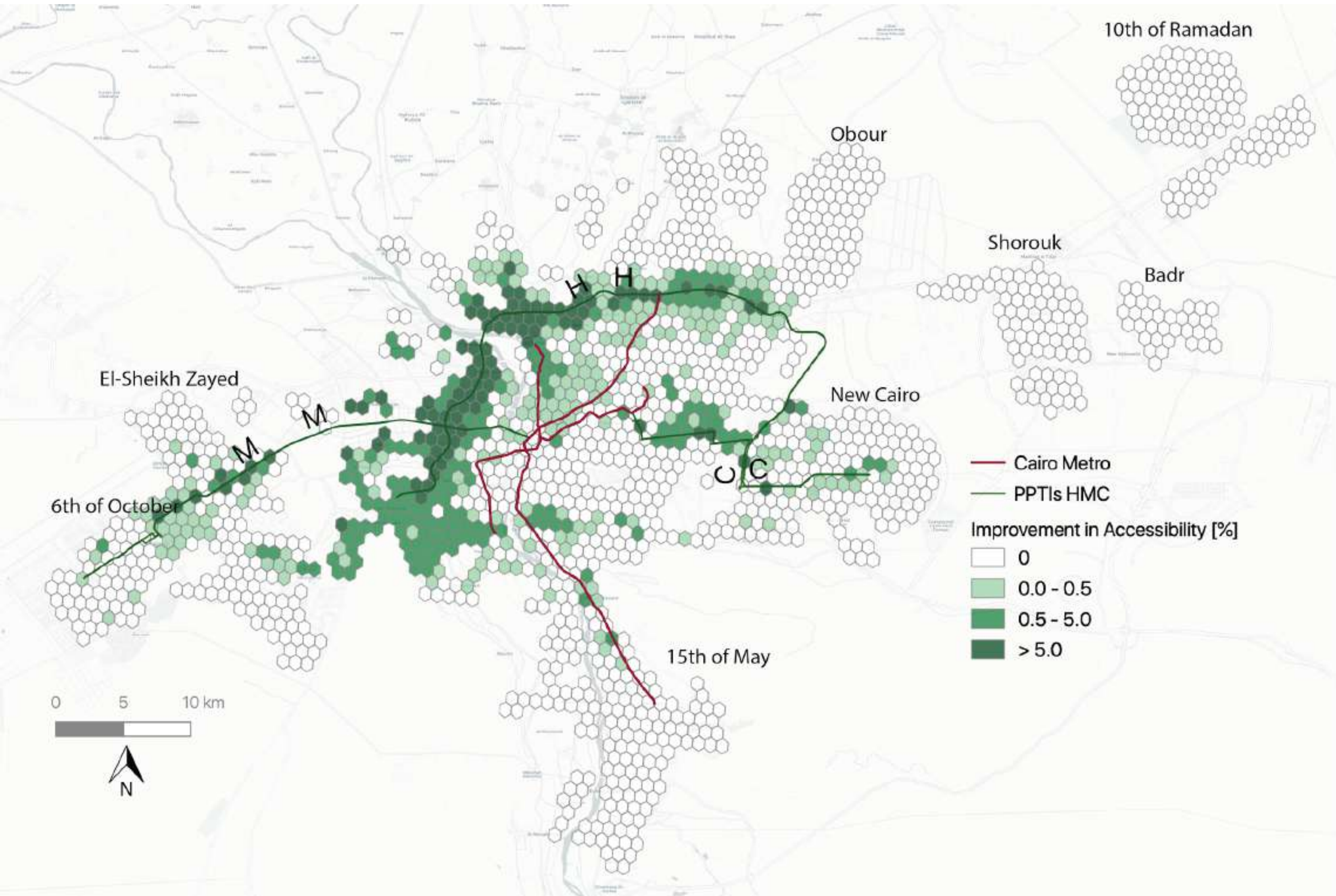


Figure 29. Map of Improvement in Job Accessibility due to Final PPTI Recommendations.

Through the consideration of both qualitative and quantitative improvements to the GCR's transit situation, it is recommended to apply key bus routes on the H, M, and C corridors which run on the following main arteries in the city:

- Corridor H (Ring Road - North) runs along the northern half of the Ring Road from Waslet El-Wahat (The Wahat connection) in the West all the way to Sadat Road outside the Police Academy in the 1st Settlement in New Cairo. It connects to the Cairo Metro Line 2.
- Corridor M (Industrial Zone - El Esaaf) runs along El-Mehwar EL-Markazi (The central Axis) of 6th of October and then along the Mehwar/26th of July highway into Giza, passing over Zamalek using the 15th of May bridge and ending at Abd El Moneim Riad station in central Cairo. it connects to the Cairo Metro Line 1 at New El-Marg station.
- Corridor C (Youssef Abbas - AUC) runs along major arterials in Nasr City (Youssef Abbas, Mostafa El-Nahhas/ Afrikia, Mahdi Arafa, Ahmed Zomor, and Ring Road) and then along the Southern Road 90 in New Cairo until outside the American University In Cairo;

The improvements in accessibility are distributed over several NUCs and inner city areas as shown in Figure 29. On the eastern side, 6 October and El-Sheikh Zayed witness an improvement of 0.2% (more 13600 jobs) and 0.43% (29240 jobs) respectively. On the western side, New Cairo improves by 0.43%. A 1% improvement in job accessibility translates to about 67000 more jobs within 1-hour reach to residents. This may not be a large total number of additional jobs accessible because the accessibility is already realized by informal transport on that route. The corridors of the PPTIs are already hosts to informal and formal public transport routes that are available to those who must ride them. The benefit will be in converting current drivers to ride a PPTI that is comfortable, secure, and reliable and thus take cars off these roads.

To compute the number of beneficiaries of any particular PPTI intervention, the number of citizens living in each area which experiences an increase in accessibility is counted. The percentage gain in accessibility is normalised to the total number of employment opportunities in the GCR, yielding how many citizens benefit to an increased access to how many jobs, each. Results are shown in Table 12.

The exercise was repeated using an alternative 75 min cutoff time for accessibility. This means, that the accessibility gain using a travel time of up-to 75 minutes of total travel time is computed. This cut-off is not optimal from a user experience point-of-view. The increased cutoff time was however chosen to account for the long distances of the NUCs to central and inner Cairo.

Table 12table 8. Total Number of Beneficiaries by number of new jobs reached after PPTI, by gender.

Number of Beneficiaries who can reach	60 Minute Cutoff		75 Minute Cutoff	
	Male	Female	Male	Female
up to 10 K Jobs	1,040,754		1,827,997	
	542,939	497,815	954,586	873,411
up to 100 K Jobs	285,513		1,060,719	
	150,212	135,301	553,972	506,747
up to 650 K Jobs	130,589		657,867	
	69,249	61,340	343,188	314,679
up to 1 Mil Jobs	23,132		466,480	
	12,035	11,097	244,019	222,461

4.2.2.3. 75 Minute Cutoff for Accessibility

If a 75 minute cutoff is used in the indicator to count the number of jobs within reach from every origin in the city, a drastic improvement in accessibility is witnessed. Results are shown for illustrative purposes.

Table 13. NUC regional and metropolitan accessibility given 75 minute cutoff.

City	A (Present)	B (Future Base)	HMC
10th of Ramadan	0.55	**0.55**	0.55
15th of May City	3.81	**4.21**	4.23
6th of October	4.95	**5.13**	5.71
Badr City	0.45	**0.45**	0.45
El Sheikh Zayed City	5.10	**7.26**	9.79
El Shorouk	3.37	**3.59**	3.59
New Cairo	19.59	**21.46**	22.10
Obour City	8.49	**9.76**	9.77
Metropolitan	31.25	**41.51**	45.21

Table 14. Non-NUC regional and metropolitan accessibility given 75 minute cutoff.

City	A (Present)	B (Future Base)	HMC
Cairo_Inner	23.70	**35.15**	35.41
Cairo_Outer	1.85	**5.12**	5.13
Cairo_central	41.96	**55.04**	56.87
Giza_Inner	18.47	**23.57**	29.46
Giza_Outer	11.86	**28.48**	29.75
Giza_central	40.29	**53.33**	59.50
Qalyoubia_Inner	12.75	**17.66**	23.21
Qalyoubia_central	37.68	**49.13**	56.90
Metropolitan	31.25	**41.51**	45.21

4.2.3. Far Future Accessibility Situation

With the recommendation of the H, M, and C corridors to host PPTIs in the future, we would also like to gauge the overall effect on accessibility of combining them with projects that are likely to be completed in a far future horizon of about 15 years from 2019. These projects are the Eastern and Western Monorail projects connecting the NUCs with the inner city as well as the High Speed Rail that is envisioned to connect Ain Sokhna with New El-Alamein on the mediterranean coast. Since the Monorail routes share the same main corridors, we do not expect the accessibility to improve drastically over that gained by the HMC PPTI recommendations.

Table 15. Accessibility Analysis Results of the Far Future Scenario (Monorail and High Speed Rail) with and without the recommended PPTIs

City	A (Present)	B (2022 Baseline)	HMC	Far Future without PPTI	Far Future with HMC
10th of Ramdan	0.15	**0.15**	0.15	0.15	0.15
15th of May City	1.44	**1.49**	1.49	1.49	1.49
6th of October	3.78	**3.86**	4.06	3.78	3.97
Badr City	0.22	**0.22**	0.22	0.22	0.22
El Sheikh Zayed City	1.31	**1.79**	2.22	2.00	2.39
El Shorouk	0.57	**0.57**	0.57	0.57	0.57
New Cairo	5.71	**5.87**	6.30	6.52	6.88
Obour City	2.85	**3.11**	3.11	3.11	3.11
Cairo_Inner	10.68	**18.58**	18.71	18.82	18.95
Cairo_Outer	0.10	**0.51**	0.51	0.51	0.51
Cairo_central	24.43	**33.54**	34.25	34.83	35.33
Giza_Inner	9.21	**12.19**	15.98	12.47	16.00
Giza_Outer	4.53	**13.24**	13.51	11.62	11.83
Giza_central	25.50	**35.15**	39.40	35.46	39.72
Qalyoubia_Inner	5.75	**7.85**	11.45	7.85	11.52
Qalyoubia_central	20.57	**27.58**	31.99	27.59	32.17
Metropolitan	17.59	**24.49**	26.70	25.04	27.17

We can see from table 15 that the accessibility situation improved 2.2% on the metropolitan average with the addition of H-M-C PPTIs only. Moreover, the addition of the Monorail and HSR only (Far Future without HMC) does not improve much over the Baseline in 2022. However, the monorail, HSR, and H-M-C PPTIs together produce the best results with a metropolitan average of 2.7% above the 2022 baseline.

4.3. 10 Park and Ride facilities for future PPTI interventions

Park and Ride (PnR) Facilities are garages near transit stations that serve to convert personal vehicle drivers to public transit riders. They are generally found on the outskirts of dense cities where traffic jams and high parking costs can deter drivers from completing their trip by car. PnR are especially beneficial in low density areas where local bus services do not cover a wide area. It is important to highlight the potential for multi-modal transportation at these PnR facilities since they can act as instigators to transit-oriented development as well as hubs for pedestrians and cyclists to park their non-motorized vehicles and utilize the PPTIs for long-range travel. The section will consider each PPTI separately and recommend locations for PnR facilities in each NUC or region served by that PPTI.

The method followed will be to utilize the information obtained from the travel time analysis, as summarised in the choke point identifications, as well as the ride-hailing data analysis to identify existing transit hubs for incorporation into a PnR facility. The benefit of a PnR facility will be realized to commuters if they can completely avoid traffic jams using their vehicles and ride the PPTI before any choke points. The ride-hailing data analysis has shown that the highest numbers of rides originate from the 3 NUCs that are served by our recommended PPTIs, so their locations will inform the ideal location of PnR locations. The PnR candidate locations are numbered from 1 to 10, starting with the Western side of the GCR in the following section. Details on the method used for the location choice can be found in Appendix G.

Parking; Cycling; Ride-hailing and Transit Feeder services

The Park and Ride of the future is a multi-modal hub for different transport modes

Park and Ride Facilities can be economically and socially viable if they are more than a simple parking lot near a transit station. Since travel demand for work commuting will focused on weekdays and rush hours, a multi-functional PnR facility that attracts travelers on recreational and service trips will justify the significant price of the construction of the facility (Krasic and Lanovic, 2013). This can be achieved by building the facility like a small shopping mall with street-facing shops and a multi-story parking garage on the interior. The shops can attract and benefit from passenger foot traffic while simultaneously giving the street a lively exterior. Rent from the shops can also be applied to maintain the facility's cleanliness and design. In addition to servicing drivers, the facility can also house bicycle parking lots and bike-sharing docks which would significantly increase its coverage area, drawing from a much wider radius of residents who can now cycle within the expected 10-20 minute cut-off.

With the growth of ride-hailing services and informal transit feeder services, there can also be a designated area for other modes to utilise the facility smoothly. The investment in a PnR facility that caters to pedestrians, shoppers, cyclists, informal transit users, ride-hailing users, as well as drivers is a future-proof way to ensure its economic and social viability and sustainability.

4.3.1. Western GCR PnR Locations

The Western NUCs being served by corridor M (Industrial Zone - El Esaaf) are 6th of October City and El-Sheikh Zayed City. These NUCs also contain origins from the list of the highest frequency origin destination pairs found in the ridehaling dataset. Figure 30 shows the locations of the PnR facility candidate locations on the 26th of July corridor, the main axis that runs through both NUCs. The locations are all close to existing transit hubs in order to effectively benefit from the multimodal nature of these hubs.

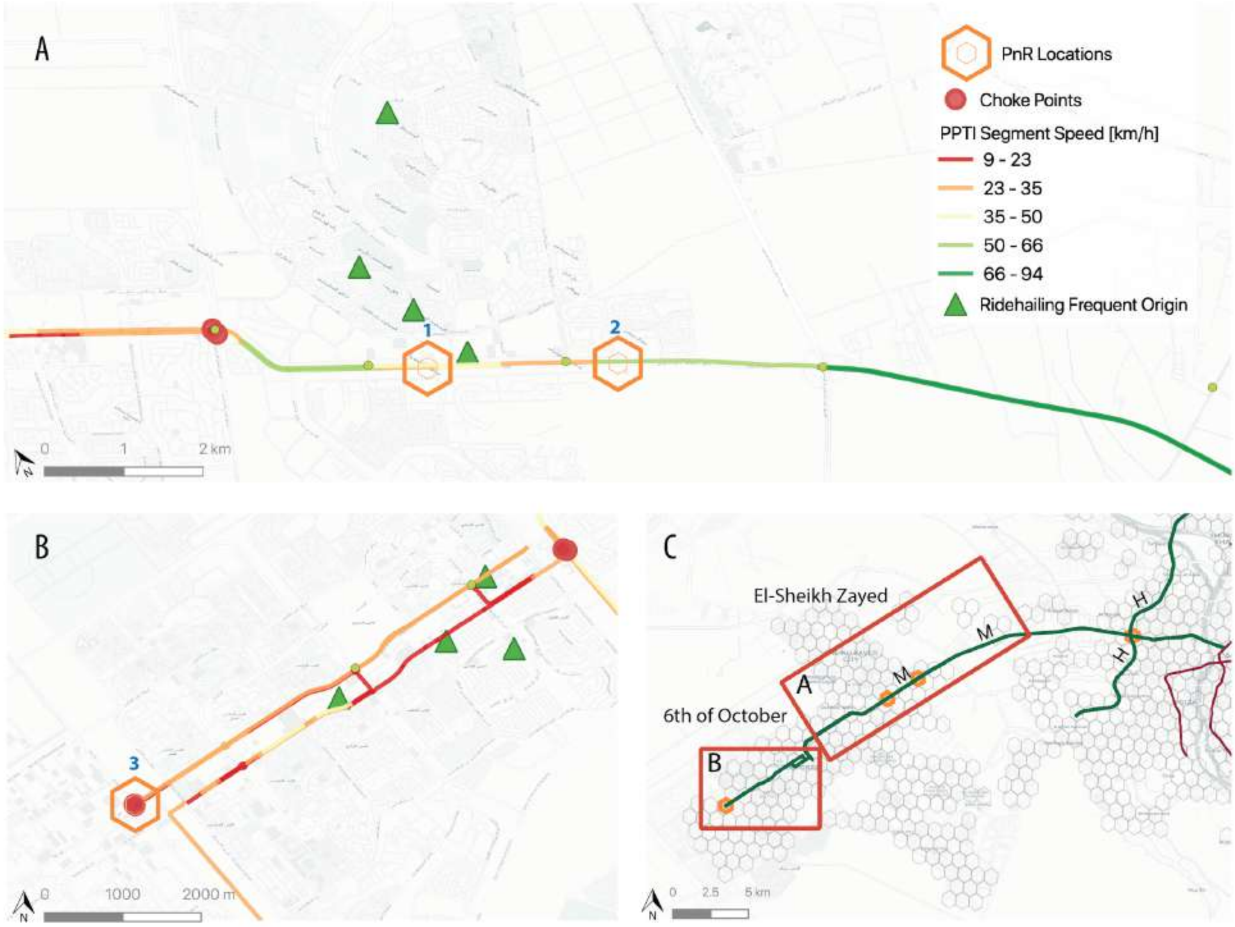


Figure 30. Map of PnR Candidate Locations in West GCR

4.3.2. Eastern GCR PnR Locations

Similar to the locations identified for PnR around 6th of October City and El-Sheikh Zayed City, three locations were identified around the PPTI that starts in Nasr City and ends in New Cairo. PnR location 4 is at the crossroads of two main arterials in Nasr City. It will serve the commuters going in the direction of New Cairo as it becomes a financial services and retail destination. On the other side, locations 5 and 6 straddle the Ring Road highway to serve the North and South Teseen roads of New Cairo respectively. For commuters who wish to leave their cars behind in the suburbs, these PnR locations offer an alternate way to get to Nasr City and connect to the center of the GCR. Finally location 7, outside the American University in Cairo, already has a Park and Ride facility operated by Mwasalat Misr and is a prime location for covering the areas in New Cairo to the east of Lotus. The exact locations are shown on the map in Figure 31.

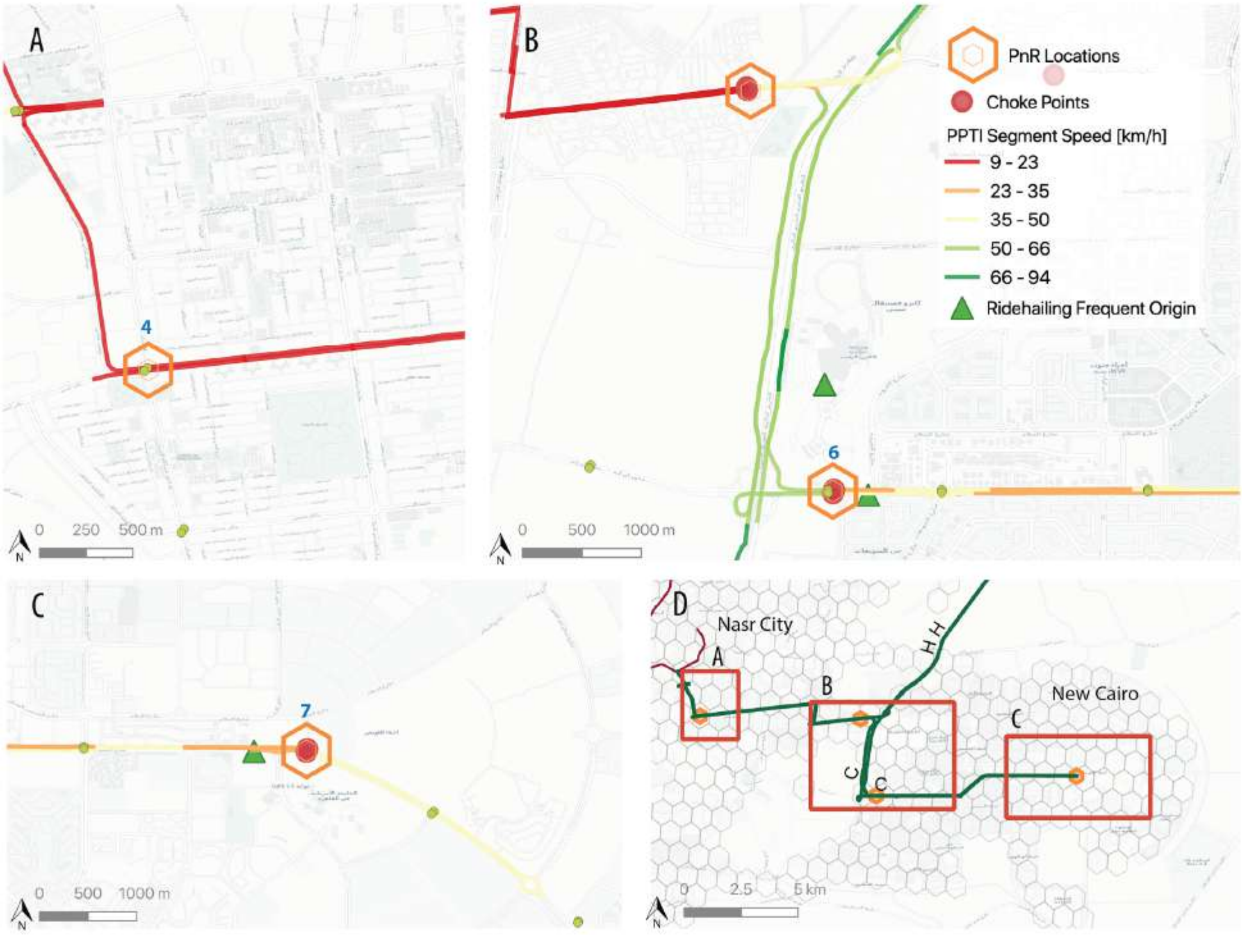


Figure 31. Map of PnR Candidate Locations in East GCR

4.3.3. Northern GCR PnR Locations

The PnR locations on the northern portion of the ring road PPTI were not chosen based on congestion since the Ring Road exhibits relatively high average speeds throughout the day. Rather, they were chosen as possible entry points for commuters and travelers from governorates to the north of Cairo and even Qalubiya to utilise the PPTIs instead of driving. PnR Locations 8 and 9 are located at the intersections of the Ring Road with the terminal station of the Cairo Metro line 1 (New El-Marg station) and the Cairo-Alexandria Agricultural Road. Finally location 10 is at the intersection of the RIng road with the 26 of July corridor (Mehwar) connecting Giza with the western NUCs. It serves two PPTI corridors simultaneously as seen in Figure 32B.

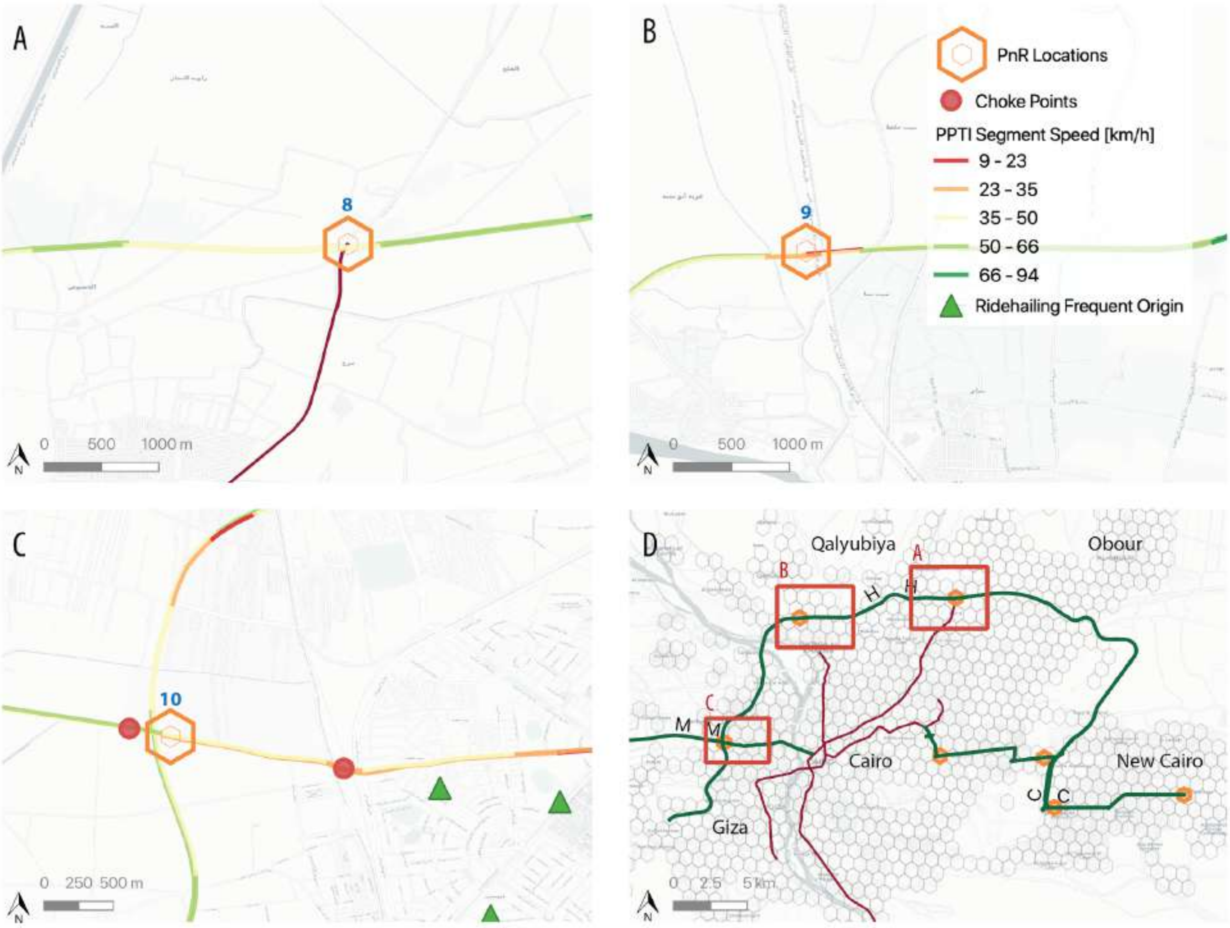


Figure 32. Map of PnR Candidate Locations in North GCR

4.3.4. Details of 10 PnR Facility Candidate Locations

Table 18. shows the cross street locations and the areas and PPTIs served by each PnR candidate location.

Number	Address	Neighbourhood	Area	Corridor
1	26 July Axis and Zohoor St.	El-Sheikh Zayed	West	M
2	26 July Axis and Nozha St.	El-Sheikh Zayed	West	M
3	El-Mehwar El-Markazi and 23rd St.	6th of October	West	M
4	El-Tayaran St. and Ali Amin st.	Nasr City	Central - East	C
5	Ahmed El-Zomor and Ring Road	1st Sett., New Cairo	East	C / H
6	South Teseen and Ring Road	1st Sett., New Cairo	East	C / H
7	South Teseen at Zone 4 outside AUC	1st Sett., New Cairo	East	C
8	El Gomhoreya st and Ring Road at New El Marg Metro Station	El-Marg, Cairo	North	H
9	Cairo-Alexandria Agricultural Road and Ring Road	Mit Nama, Qalyubia	North	H
10	26 July Axis and Ring Road	Warraq, Giza	North - West	H / M

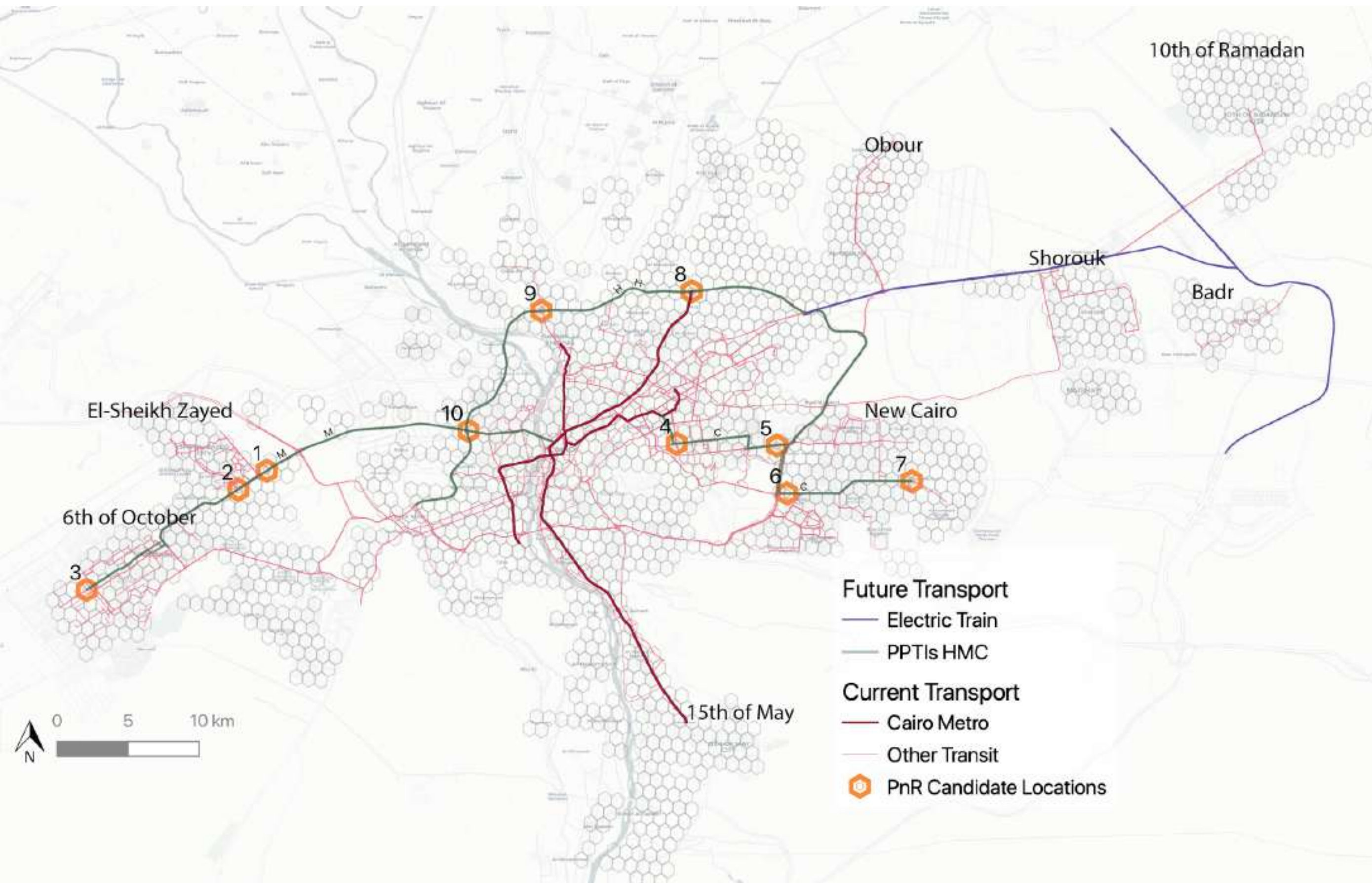


Figure 35. A Map of all Park and Ride Facility locations

5. A Holistic View of Mobility

5.1. Intelligent Transport Systems

5.1.1. Road Transport "Smart" Systems

"Intelligent Transport Systems (ITS) are advanced applications which without embodying intelligence as such, aim to provide innovative services relating to different modes of transport and traffic management and enable various users to be better informed and make safer, more coordinated and 'smarter' use of transport networks"

Directive 2010/40/EU of the European Parliament and of the Council of 7 July 2010, Official Journal of the European Union

Although Intelligent Transport Systems (ITS) usually apply to road transportation systems as noted above by the official journal of the European Union, its benefits and motivations can be applied to all modes of transport. Our recommendations are for Potential Public Transit Interventions (PPTI), which are likely to be BRT systems or dedicated lanes for high capacity vehicles. Either mode of transport would inevitably operate alongside other vehicular traffic on the road network. Improving the entire road network with "smart" solutions would result in improved PPTI performance.

ITS enables commuters or traffic engineers to be better informed while making decisions about travel and traffic management. For example, traffic data can be displayed to travelers through the internet via smartphone applications or published on a digital screen on the side of the road. For this information to have a positive effect on travel experience, it must reach the decision-maker at an appropriate time, either before they choose the mode that is contributing to traffic or if they are already on their journey, then before the choice to switch modes has passed. For example, if there is traffic on a particular route serviced by a PPTI, information regarding traffic delays should be placed before an entrance to a PnR facility to enable the driver to switch to the PPTI before getting stuck in the traffic.

Another intelligent transport system element is the application of congestion pricing. Congestion pricing would sense the presence of a car within a zone, usually in the dense urban center, and apply a fee to the driver for contributing to the traffic in that zone. It is applied in very few urban centers in the world but experiments have shown positive effects on traffic reduction in London (Santos 2004). Dynamic congestion pricing would adjust the fee charged in the congestion zone to increase and decrease dynamically to further control the flow of traffic.

Most benefits to the travel experience using ITS are dependent on infrastructure that collects real-time data on the usage of the road network as well as infrastructure that controls the flow. Examples of the former are traffic cameras or sensors that inform a central planning unit. Examples of the latter include traffic lights and reversible lane signals. In the future, even the direction and availability of entire streets can be changed dynamically by sending an electronic signal through the control infrastructure. Unfortunately, these two necessary systems are largely unavailable in the GCR. For that reason, ITS is still far from being applicable on a city-wide road infrastructural level. On the other hand, incremental change can be applied more easily in the non-personal vehicle infrastructure developed as part of public transit systems. The following section details several applications of sensors and control infrastructures on the level of the public transport system.

5.1.2. Automatic Fare Collection and Integrated Ticketing

Current trends of public transport investment in the GCR show that options will be increasing for commuters. The existence of many forms of transport increases the city's resilience by creating a multitude of options for commuters.

As the network grows more complex, the system's potential may not be fully utilized by the public. Out of an endless combination of multi-modal trips, commuters may refrain from taking certain options due to the high level of discomfort at every transfer. If each transfer requires a separate ticket, then the appeal of the trip drops with an increase in transfers. Chipping away at the bureaucracy is a necessary step that needs to be taken as the new services come into play.

The discomfort associated with transfers can be overcome through two related but not identical steps. The first is an Automatic Fare Collection (AFC) System which allows commuters to use an electronic card to access the service instead of cash. The second step, which requires the cooperation of the largest service providers, is Integrated Ticketing whereby a single ticket and card can be used to access more than one service provider's vehicles. The more transport service providers that are integrated into such a system, the easier commuting becomes. Transfer time decreases and more options become appealing due to more seamless transfers. The following sections highlight some of the expected benefits of introducing an integrated ticketing solution:

5.1.2.1. Enabling Multimodal Trips

Integrated Ticketing has been adopted in various forms around the world. The underlying principle is the same: One ticket gives the user access to all modes of public transport in the city, regardless of the operator.

Integrated Ticketing is usually implemented after AFC has been introduced, meaning that users only need to swipe a smart card when boarding or alighting from any vehicle. Once both AFC and Integrated Ticketing are implemented, the following benefits, which enable easier multimodal trips, can be realised:

- Reduction to the cost of safeguarding money. With no cash involved neither the driver nor the operator has to worry about depositing the money at the end of the day.
- Removing mistrust between drivers and management by significantly reducing the chances of embezzlement by drivers, tackling one of informal transport's defining problems.
- Large reduction in time. Drivers do not need to preoccupy themselves with cash exchanges, and so spend less time at stops. Fleet efficiency increases, allowing for higher frequencies using the same number of vehicles and thus increasing operator profitability.

This time reduction applies to all bus transit modes except the larger buses run by the CTA, where a conductor collects money and provides a ticket.

5.1.2.2. Improving the existing fare policy

Automatic Fare Collection and Integrated Ticketing not only make for a seamless travel experience but also allow for the adjustment of fares in a way that benefits both users, operators, and society.

There are two broad fare mechanisms used by operators:

Flat fares: Fares are fixed by service, regardless of distance actually travelled.

Distance-based fare: Fares vary according to distance traveled.

Integrated ticketing allows the transition from flat pricing to distance-based pricing. This creates a big incentive for people to take multi-modal trips, as the price is based on distance and not fixed for each service. An increase in ridership means that additional revenues can be used to improve the system, attracting even more people to choose public transportation.

5.1.2.3. Shifting towards a targeted Mobility Subsidy Scheme

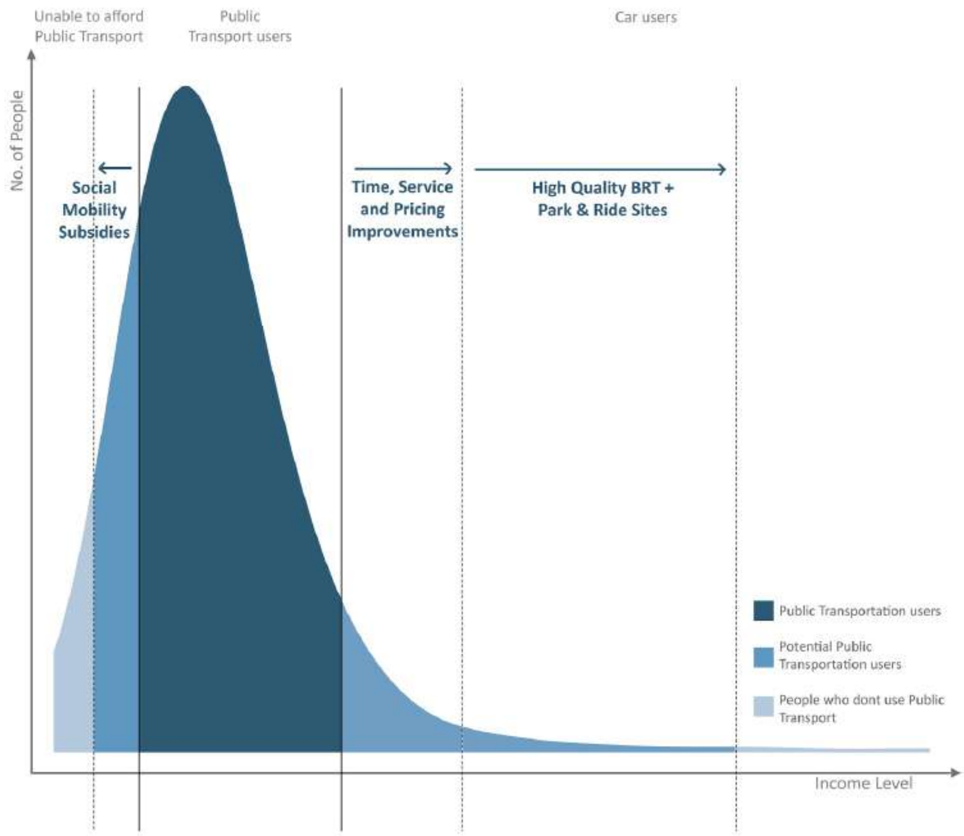
Distance-based pricing makes trips more expensive for people that live on the outskirts of the city and commute long distances every day. These are normally the poorest segments of society who depend on public transport the most. The average urban dweller spends 7.4% of income on transportation, a share that increases with poverty and with distance to centers of employment.

A potential solution lies in targeting low fares for low income households. Increasing standard fares enabled by integrated ticketing gives room for offering special pricing for regular commuters and subsidizing trips for vulnerable groups. Such a Mobility Subsidy Scheme should be integrated with the already existing Unified National Registry which manages social security and food subsidy smart cards (بطاقة تموين).

An Egyptian precedent exists in the new local Food Subsidy ration card system, which allocated EGP 15 per person per month. This offers consumers the choice between a wider variety of food commodities compared with the old food ration system which subsidised only oil, rice, sugar (Abdalla and Sherine 2017). In a similar fashion, Integrated Ticketing could expand the potential Mobility Subsidy Scheme to formal and informal transit providers. Consumers would benefit from a more diverse range of services offered, while public operators such as the Egyptian Metro Operating Company (EMOC) and the CTA could raise prices to fund improvements in quality of service.

Figure 33: Expected Impact of Service and Pricing Improvements on ridership.

Density map of Egyptian income distribution based on the LHS 2015.



The people density distribution corresponds to the actual distribution of income levels across Egyptian Society, as represented by the Labor Force Survey 2015.

It shows how service and pricing Improvements can shift some car-users to find public transport more financially attractive and physically comfortable.

It also shows how targeted Social Mobility Subsidies could expand public transport usage amongst those unable to afford public transport, and counter any potential increases in the standard fare. Everybody would benefit from the service improvements.

Background Box 10: Integrated Ticketing - Examples from around the world

Example I : Single tickets in Sao Paulo, Brazil

The São Paulo State Secretariat for Metropolitan Transportation (STM) started integrating fares amongst its three Operators in 2004, starting with a single fare that permits users to take up to four services within a three hour time period. It was later expanded to a 'monthly ticket' which allowed unlimited travel between all three networks.

Example II : Central Clearing House in Curitiba, Brazil

The transport authority of Curitiba, Brazil (URBS) coordinates the activity of 28 private operators in the Metropolitan Region of Curitiba. It collects all the revenue in a central account and redistributes them among the operators according to vehicle type and kilometers covered. It does not distribute proceeds based on the number of passengers transported, preventing on-street competition between operators.

Example III : Carte Orange in Paris, France

When the Carte Orange was introduced in Paris in the 1970s, bus ridership jumped by 40% within a year (Montgomery 2013). Even though the card did not make trips much faster or cheaper, the fact that it made transfers hassle-free was enough incentive for people to ride the buses more.

Source: (CODATU and Ministry of Ecology, Sustainable Development and Energy (MEDDE) 2014)

Example IV : Tap n' Go cards in Kigali, Rwanda

In 2013 the City of Kigali formalised its multitude of informal operators into three operating companies. A single stored value payment card, commonly referred to as "Tap n' Go" was introduced as the only acceptable method of payment. Stored Value payment cards store a monetary value on the card itself, rather than in an external account maintained by a financial institution. A private company was contracted to handle the IT-Infrastructure and provide card recharging at every stop by means of a portable Point-of-Sale terminal, in exchange for a small commission on every ticket sold. At present, public transport in Kigali is 100% cashless.

Example V : Financial Inclusion in Mexico City, Mexico

In Mexico City, the Electric Transport Service of the Federal District (STE) started issuing reloadable debit cards using EMV® contactless technology instead of regular stored value cards. In many cases, these cards provided unbanked people with their first formal financial tool, which is also usable at any mobile point of sale terminal or for internet purchases.

5.2. Multimodality

Commuters choose their mode of transport based on quality of service, socio-economic standing and personal health conditions, the area in which movement will take place and more. The User Experience model (Figure 2) shows how total cost and trip duration in time vary, and inevitably determines which mode users pick: The fastest, most affordable one they know and consider adequate. (Abdelaal et al. 2017)

Intelligent transport systems at the road level, and at the public transport system level, enable multimodality and can improve travel time, trip cost and service adequacy. However, the question remains: Are the proposed PPTI's *better* than the existing transport network?

This study chose to utilise the concept of "potential public transport infrastructure / intervention" (PPTI), so as not to presume a preference for any kind of infrastructure over any other (Such as public buses, Bus-Rapid-Transit, congestion protection for collective transport, light-rail-transit, etc). The detailed choice of infrastructure is out-of-scope of this study, and rather a matter pertaining to design/funding/time constraints and public consultation. However, it is assumed in the model that the PPTI will be shielded from traffic with its own right-of-way.

Since we believe that the PPTI could be any form of infrastructure, we propose an unusual intervention for each identified top three corridor. Each blue box is inspired by an international experience and meant as a prompt for further discussion, study and choice. We also examine the competitiveness of individual modes, the risks of trying to replace - and the opportunity of working as partners with - the informal transit operators.

PPTI Proposal: Corridor H (Ring Road - North) ***Stations inspired by Dubai***

The route of the elevated Dubai Metro Red Line is adjacent to the Sheikh Zayed corridor, which acts as the vertical spine of the city of Dubai. Most stations are elevated, and include an air conditioned footbridge connecting the eastern and western side of the Sheikh Zayed corridor. Stations are distanced approximately 1 km from each other, and form the main infrastructure for pedestrian crossing of the busy highway, improving accessibility. Each metro station has a bus stop and drop-off area for taxis; most stations have limited parking. Signs to the stations are provided in the surrounding area, and designated to motorists (on roads), cyclists (on adjacent cycling paths) and to pedestrians in the area. Information inside the station shows the adjacent area, the metro route network and the feeder bus network.

A potential intervention on corridor H could see dedicating the innermost two lanes in each direction solely for formal buses and informal transport microbuses operating across the corridor, and providing services to the eastern and western NUCs. A network of stations is constructed, providing PnR and taxi / ride-hailing drop-off points, integration with local transit feeder networks, pedestrian footbridges crossing Corridor H, pedestrian landscape and softscape enhancements in the surrounding area and intermodal connections to adjacent metro and rail infrastructure:

- Line 1 terminus "New Marg" crosses Corridor H.
- Line 3 future terminus Adly Mansour Stop will be an intermodal station, and connect the Cairo Metro with the Electric Train to the New Administrative Capital.
- Line 2 is currently examined for a potential extension to Qalyub, crossing Corridor H.

Source: (WikiArquitectura n.d.) (Al Suwaidi et al., n.d.)

5.2.1. The Risk of in-corridor competition

The successful implementation of any public transport infrastructure / intervention (PPTI) on the suggested corridors would require engaging the existing formal and informal modes of transport already providing services at the end points of said corridor within the NUCs, and services utilising said corridor connecting NUCs with other destinations in inner and central Cairo.

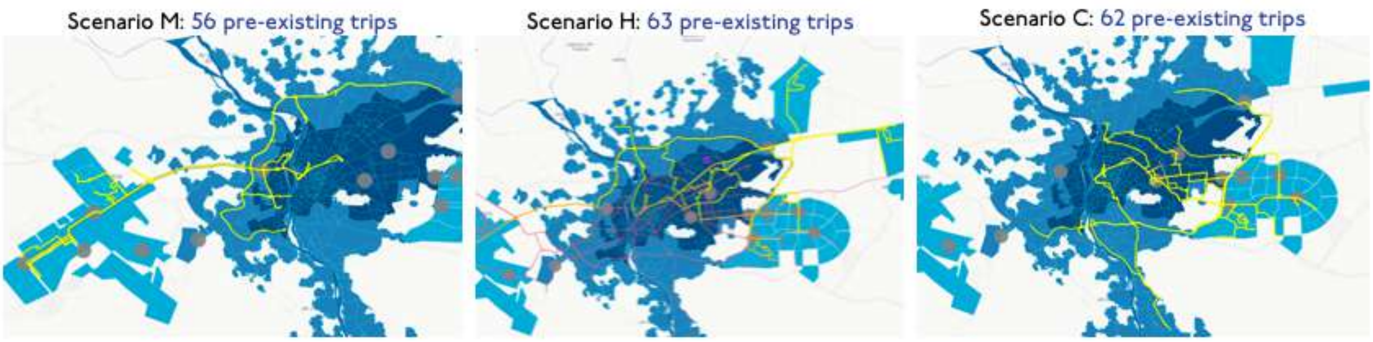


Figure 34: Pre-existing public transit routes (Yellow) operating on each PPTI Corridor / Scenario

Figure 34 selects and counts all unique public transit routes for each corridor:

- **Scenario M** (Industrial Zone - El Esaaf): There are 56 unique public transit trips which operate on the corridor segment starting at the Ring Road and ending at the Alexandria Desert Road. The visualisation clearly shows how these services cover a large section of El-Sheikh Zayed City and 6th of October City, as well as the western side of Inner Cairo.
- **Scenario H** (Ring Road - North): There are 63 unique public transit trips which operate on the corridor segments of the Ring Road itself. The visualisation clearly shows how these services connect El Obour, El Shorouk and New Cairo, as well as the northern and eastern Inner Cairo.
- **Scenario C** (Youssef Abbas - AUC): There are 62 unique public transit trips which operate on the corridor segment starting at the Ring Road and ending at the American University in Cairo. The visualisation clearly shows how these services cover a large section of New Cairo, as well as most of eastern and Inner Cairo.

These visualisations serve as evidence of the existing public transport system providing a multitude of direct point-to-point services. There are many reasons such parallel routes emerge and persist: First, informal transport operators currently operate in an open market situation adding routes organically where demand manifests itself. This leads to a market failure situation, where the fragmentation of operations prevents rational supply networks. Second, formal bus operators such as the CTA plan routes primarily based on the availability of new buses coming in to CTA or by requests from different groups of citizens or authorities. The ad hoc case-by-case nature of planning leads to constant changes in terms of new and existing routes and to abandoned routes. (ACE Consulting Engineers and COWI 2016; Cairo Governorate).

Peak-only commuter services, while not visualised, also provide such services. While such services are subject to traffic congestion, particularly at peak-hours, they can often be faster than the feeder-trunk-distributor model a PPTI would likely elicit.

Replacing direct point-to-point informal services with feeder-trunk-distributor services represents a significant change for both passengers and operators, and requires careful analysis of probable impacts and recognition and integration of the informal sector, potentially through parallel and periodic regulatory changes.

The Journey Gap is the difference in total trip time (Figure 2) between taking different modes of transport. A big Journey Gap between private cars and public transport is one of the primary determinants of those who opt to drive. The same applies on which mode of public transport passengers choose. Making the PPTI compete successfully with existing services and maximising the accessibility gain is thus about reducing this journey gap to a minimum on as many itineraries as possible, and making it negative (i.e. the PPTI feeder-trunk-distributor service is faster than a point-to-point service).

PPTI Proposal: Corridor C (Youssef Abbas - AUC) ***Integrating, not transitioning informal transport***

The *TransMilineo* in Bogota, Columbia is the exemplar BRT system in terms of speed and capacity. It consists of a system of segregated trunk corridor routes and a system of feeder services operating in mixed traffic acts to transport passengers to and from BRT stations.

Most of Bogota remains outside of the BRT trunk and feeder service catchment areas. As existing informal transport vehicles were displaced from the two BRT corridors, they simply moved to other corridors. Total travel times and congestion levels increased over the entire urban system, hampering the ultimate system level impacts. The total number of informal transport vehicles increased, and by 2010 BRT services were responsible for approximately 20% of all public transport trips, with informal transport responsible for the remaining. The city recognized the limitations of the original strategy, and started implementing a revised strategy in 2012. informal transport operators were not to act solely as feeders to BRT, but be allowed to operate full service as long as they are formalized and win a tender contract to operate within one of 12 designated zones.

Corridor C corresponds to the same itinerary as the proposed eastern BRT currently undergoing a feasibility study and overlaps with most of Metro Line 4 (within Nasr City) and the proposed eastern Monorail (within New Cairo). The existence of multiple parallel corridors in Nasr City and New Cairo, as well as the multitude of connections between both, make the displaced competition scenario seen in Bogota very likely.

A potential intervention on Corridor C could see transitioning the target areas to a hybrid public transport system where formal and informal systems coexist and complement each other. This can take multiple forms:

- Designing, regulating and incentivising informal transport to work in a feeder-trunk-distributor framework with the expected future infrastructure.
- Permitting informal transport into a formal, scheduled system during high-demand peak periods.
- Concessioning, franchising or using other regulatory and incentivising mechanisms to support informal transport quality-of-service improvements and complementary hybridity.

Source: (Behrens and Ferro, 2015) (Jennings, G & Behrens, R 2017)

PPTI Proposal: Corridor M (Industrial Zone - El Esaaf) ***How not to repeat the mistakes of South Africa***

Corridor H is the site of multiple proposed transport interventions:

- The western monorail connecting 6th of October and Sheikh Zayed to Giza.
- An early proposal utilizing the Mehwar/26th of July highway for a high specification BRT was considered, and then shelved
- Five (out of eight) BRT Light services to be provided by Mwasalat Misr take the Mehwar.

The Mehwar/26th of July highway is the only direct opportunity to enter inner/central Cairo from the western NUCs. (The new Rod-El farag highway to be opened starts and ends 5km to the north). It exhibits high congestion at both its beginning and end; and low commercial speeds at peak hours. The highway is problematic for cars and an opportunity for transit, it seems.

However, as Table 12 shows, the Accessibility gains of a PPTI still remain limited, particularly for 6th of October City (0.2% gain) and El Sheikh Zayed City (0.1% gain). A BRT-like PPTI would require a feeder-distributor-trunk system to work, and would still not drastically improve travel times compared to the existing point-to-point services. Previous research by TfC showed 78.6% of all areas examined within El-Sheikh Zayed City and 64.7% of all origins examined within 6th of October City to already have a transit connection to inner/central Cairo. (Hegazy et al., 2019) The average walking distance per itinerary is more than 1 km. 90% of itineraries require at least one transfer. The western NUCs are too big in area size, and too distant from centers of employment for transit to provide comprehensive connections in less than an hour of travel time.

Johannesburg, South Africa has a similar geography. Operational costs are 25-40% higher and ridership revenues much lower than anticipated, resulting in a long-term operational funding shortfall. Long individual trips result in low seat turnover (how many times a different person accesses a seat in a bus generating revenue) and a high peak-to-off-peak ratio. The informal transport sector proved far more efficient at providing long-distance one-seat rides quickly adapted to market needs and the existing urban form.

Source: (Beukes and World Bank Group 2018) (Hegazy, Kalila, and Klopp 2019)

5.2.2. The opportunity of working with informal transit operators

Background Box 12: Gautrain, and "the best operators we ever worked with."

The *Gautrain* in Johannesburg, South Africa is a greenfield metropolitan commuter rail network meant to shift road users onto public transport. As part of the local Black Economic Empowerment policy, the Gautrain Management Agency subcontracted feeder services to local shared taxi drivers, the South African equivalent of informal transit. The arrangement sees feeder shared taxi services keeping 100% of the farebox revenues and receiving a small payment and license to operate the feeder service, while respecting a set schedule and quality as well as safety standards. Early on during operation, shared taxi operators were upset about low utilisation rates and empty trips. As passengers started to rely on the feeder and Gautrain for their daily commute, utilisation rates rose. Gautrain COO William Dachs praised the new 'informal' subcontractors as the "best operators we ever worked with."

Source: Dachs. W, 2017

Ignoring the existing informal system risks deteriorating accessibility in the GCR. Insufficiently engaging the sector which historically resisted comprehensive replacement, is likely to continue to do so and provides the majority of services, and thus accessibility, in the GCR is not a solution.

Investing in a corridor might lead to excessive in-corridor competition, as is likely in Corridor M (Industrial Zone - El Esaaf). Preventing and actually enforcing a ban on in-corridor competition would only displace services to parallel routes and defer dealing with the sector, as is likely in Corridor C (Youssef Abbas - AUC). It is thus best to plan for a hybrid system from the start, as is proposed in Corridor H (Ring Road - North).

Investment Proposals must not be limited to BRT systems or rail connections. Rather, Investments could flow into:

- Incubating an accountable urban transport authority (able to plan the service network, administer regulation, and guide the development of the sector)
- Fleet renovations, and the use of such a scheme to impose an appropriate mix of obligations and incentives
- Infrastructure improvements, improving the user experience and optimising travel times to improve accessibility.

Public transport infrastructure / interventions (PPTI) could take many shapes, and still meaningfully contribute to improving accessibility and increasing the modal share of public transport. One of these forms is engaging informal transit operators into an overhaul of a section of the network.

5.3. Interventions to promote walking

5.3.1. Pedestrian Connectivity

To understand how the urban fabric facilitates walking, we compute the pedestrian connectivity for the areas considered for Park and Ride (PnR) facilities. The pedestrian connectivity is calculated as the quotient of straight-line area (circular) divided by the average pedestrian walkshed area on the road network. It is inspired by the Potential Mobility Index suggested in Martens 2015. The pedestrian connectivity of transit hubs located in Inner Cairo, namely Nasr City and Heliopolis, were computed and their average is used as a benchmark for good pedestrian connectivity. Then we compute the pedestrian connectivity for all the PnR candidate locations. This allows for a comparison of pedestrian connectivity based on geographic location. We then focus on areas with low accessibility scores and try to identify the cause. Images of the streets allow for the identification of recurring accessibility problems faced by pedestrians.

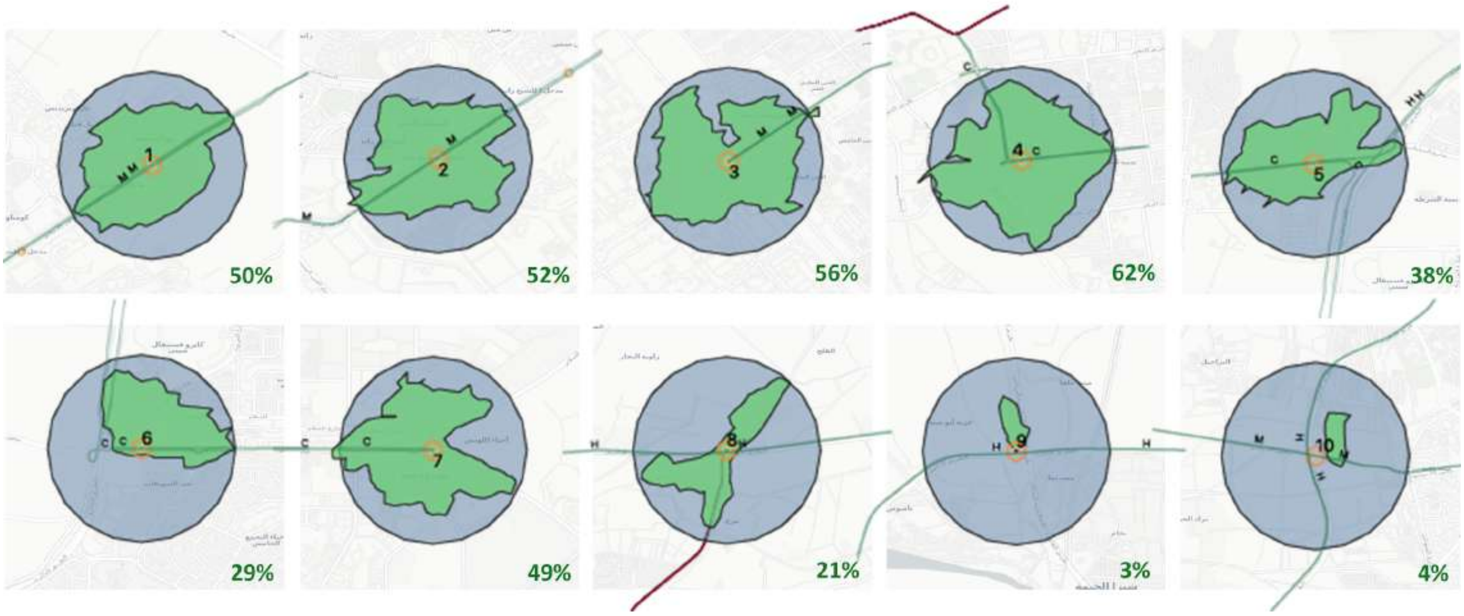


Figure 34. Pedestrian Walkshed Areas and circular areas used in the computation of the Potential Mobility Index for each Park and Ride candidate location.

Table 16: Pedestrian Connectivity Computation for each PnR candidate

PnR	PC	Neighbourhood
1	50%	El-Sheikh Zayed
2	52%	El-Sheikh Zayed
3	56%	6th of October
4	62%	Nasr City
5	38%	1st Sett., New Cairo
6	29%	1st Sett., New Cairo
7	49%	1st Sett., New Cairo
8	21%	El-Marg, Cairo
9	3%	Mit Nama, Qalyubia
10	4%	Warraq, Giza

Transit hubs located in walkable neighborhoods, which include a grid or a roundabout street design (such as Heliopolis and Nasr City) were found to have a mean pedestrian connectivity of 46%. Simply said: On average, the area reached by 10 minutes of walking along the street network is 46% the size of the area reachable if there were no streets at all.

This can be taken as a good score to be emulated in other parts of the city. Nasr City and Heliopolis have vibrant street lives and a walkable street design. The pedestrian connectivity calculations around each PnR candidate location are reported in Table 16.

Nasr City (in inner Cairo) has the most walkable street design. The western N UCs (6th of October and El-Sheikh Zayed) come next, closely followed by the Eastern NUCs (New Cairo). The worst walkability scores are in the informal settlements in the GCR where former agricultural plots were built up to house rural immigrants and no official street plan was laid out. Such a low pedestrian connectivity score for the informal settlements may also be due in part to missing roads on Open Street Maps, which is used as the street network in our computations. Maps for the walksheds and the circular area used to compute the pedestrian connectivity for each PnR location are shown in Figure 34.

5.3.2. The Walking Experience

The road network may seem accessible to foot traffic and yet be unwelcoming or uncomfortable to pedestrians. That is because the quality of a route is also an important aspect for pedestrians. The distance most people are willing to walk to transit is around 400 m (Walker 2012), but it is surely dependent on their health and level of comfort. Visually stimulating and unobstructed routes make walking seem faster and lead to pedestrians walking longer distances (Gehl 2010). Shade matters in hot conditions, as does light in dark conditions. Uninteresting routes feel more tiring and so experience less foot traffic. It is therefore insufficient to focus on accessibility scores alone as they do not capture walk appeal (Mouzon 2012).

Changing land use in the GCR to promote pedestrian connectivity is a big challenge. Another method to improve walking accessibility is to improve the quality of sidewalks. Although most sidewalks in the major streets are usually in good condition, there is room for improvement. The main feature that is lacking in pedestrian infrastructure is its continuity and interconnectedness across streets and intersections. After a brief inspection of the conditions of sidewalks in Inner Cairo as well as NUCs (Outer Cairo), a few recurring problems with easy solutions are noticeable. Pictures of these conditions are shown in Figure 35.

- Narrow or non existent sidewalks (Figure 35 A and E)
- Obstructed sidewalks (due to plant structures, built walls, different elevations with no slope, and parked cars) (Figure 35 C and D)
- Sidewalks that are under the control of private home owners planted as gardens (Figure 37 G)
- No protected pedestrian crossings (Figure 35 E and F)
- Roads that are too wide and have high speed traffic (Figure 35 E and F)

Luckily, these issues in the continuity of sidewalks and their ease of use, especially for the differently-abled and elderly, are easily fixed. If the construction of sidewalks follows a code published by authorities, a gradual consistency can be reached that addresses all of the issues outlined above.

Background Box 13: Making streets more comfortable, one step at a time

The shape of the built environment heavily influences pedestrian mobility. There are two extremes between which most cities lie:

Lifeless *Livable*

Multistory buildings, closely spaced buildings,

heavy traffic, well-designed public spaces,

While it is true that each city is different from the other, some generalization about what makes the latter description preferable can be made. All it takes is a closer look at ***human beings*** and what makes them comfortable:

- *Tiring length perspective*: People find straight routes to be a deterrent for walking. If the whole route can be seen from the beginning, the prospect of walking becomes tiring. Routes that do not go in a straight path are more interesting, as they promise change around the corner. The distance seems shorter when it is not all laid out in front of you.
- *Interesting things to see at eye level*: Having shops on ground floors gives people the option of observing and enjoying. The liveliness created by these shops makes pedestrians feel safer walking down the street. Long walks also feel shorter when there is plenty to see.
- *Making room*: Sidewalks should be wide enough to allow for unhampered movement. People should easily be able to pass by each other, whether on foot or on wheelchairs. Widening streets to accommodate car traffic at the expense of sidewalks is a sure way to make the walk less comfortable.
- *Avoiding stairs:* People are less averse to horizontal movement than they are to vertical movement. Having stairs as a necessary obstacle along a street makes it an impassable barrier for some, and a less comfortable experience for most. Ramps are generally preferred by pedestrians than stairs.
- *Protection from unpleasant weather:* Building design should be adapted to local climate conditions to reduce undesirable climate conditions. In warm regions, shaded streets provide cover and prevent radiant heat being emitted from the asphalt.

Sources: Gehl, 2010. *Cities for People*

Figure 35. Pictures showing challenges to pedestrian activity in Inner and Outer Cairo

5.3.3. Cycling Networks

Running local buses in low-density areas has a high cost per passenger for transit agencies, as ridership tends to be low. Bicycle networks are a practical way of expanding the reach of transit networks in such areas, as they reduce the demand for all-day local buses. A proper bicycle network allows residents to cycle to a nearby transit station and take an intercity service from there. The increased demand induced by such a network would allow transit agencies to operate buses at higher frequencies without incurring additional costs.

The NUCs are ideal examples of low-density areas that could benefit from cycling infrastructure. At the moment, private vehicles are the predominant mode of transportation in these areas, but a good bicycle network that connects residents to both points of interest and intercity transit could change that. Analysis of the ride-hailing dataset reveals that 43% of ride-hailing trips taken are between 1 km and 5 km in distance, and thus well within the adequate range of a typical cycling trip. Thus, there is latent demand for cycling that would only realise if adequate cycling infrastructure is built.

The catchment area of any transit hub increases if they were to be served by a bicycle network. Isochrone maps show the polygon area that is accessible within specified times by walking and by cycling. (Figure 36)

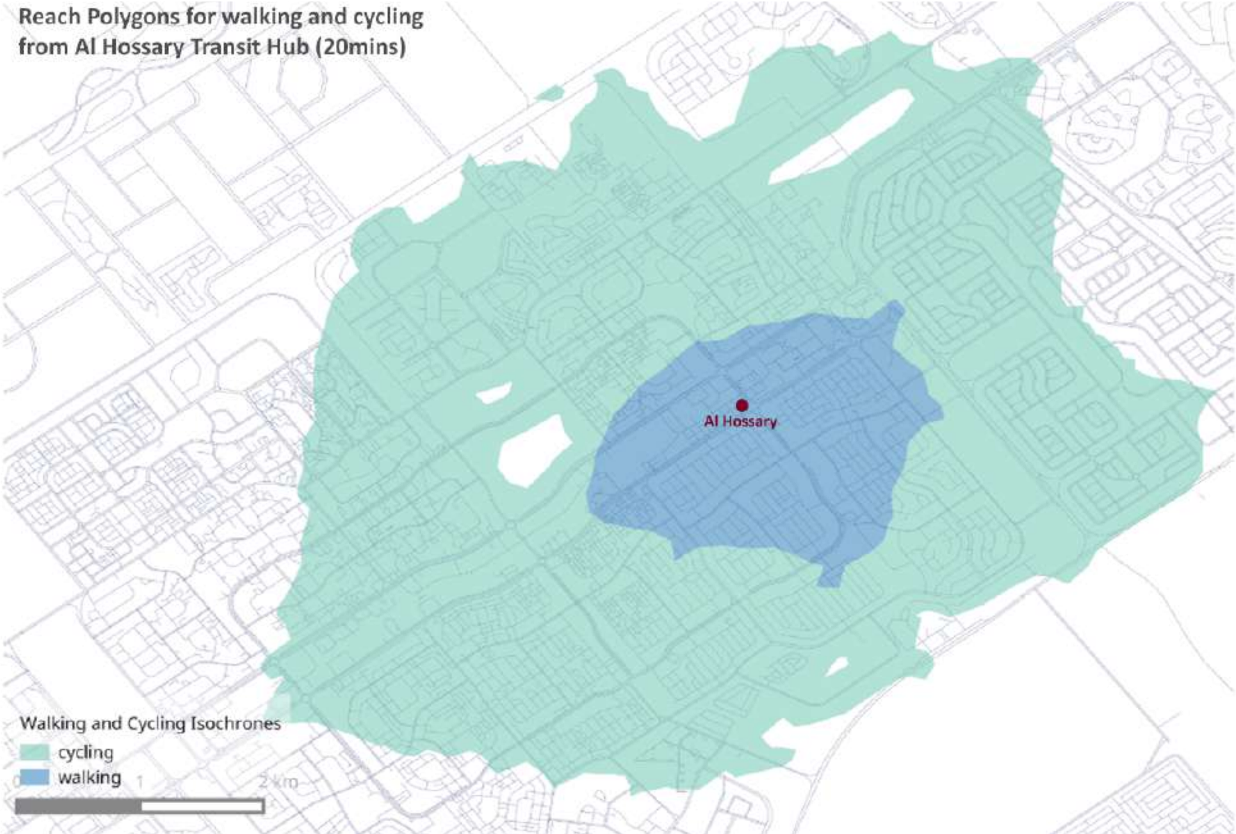


Figure 36: Example of increase in reach of cycling compared to walking

But any bicycle network is only as good as the underlying infrastructure. Isochrone maps visualizing the potential catchment area around the transit hubs immediately show the accessibility problems that would face cyclists (An example would be the South Teseen axis in New Cairo, a major artery that bisects the city from East to West, with no pedestrian crossings along it). Interventions to deal with recurring problems are suggested by looking at best practice solutions and adapting them to the local context.

6. Conclusion

What are the three optimal locations of future transit corridor investments? Where should park and ride facilities be located? How can we enhance urban mobility in the GCR the most? Working at the strategic planning dimension, this study relied on modeling, testing scenarios, and quantitative and qualitative analyses to arrive at recommendations.

To do so, we made several contributions to adjust for the data-poor context of Cairo:

(i) A spatial model for the distribution of population in the GCR; (ii) a spatial model of job density or opportunities; (iii) a temporal and geographic model of formal and informal transit data at present; (iv) and expected future infrastructure and (v) a first-in-kind analysis of ride-hailing data. Combined, these datasets allowed the first application of modern accessibility measures: A count of the number of jobs reachable from every possible origin in the city.

Thus, for each neighborhood in Cairo, and each New Urban Community in the GCR, a detailed picture of accessibility was constructed. Gaps in the ability to travel effectively using public transport were identified. Future investments were pondered, and examined: Do they fill these gaps? How effective would they be? The results are enlightening.

6.1. Details on the Findings of the Study

6.1.1. Accessibility in the Greater Cairo region

Most job locations are within the inner parts of the GCR inside the boundaries of the Rind Road. Jobs are more concentrated than people. Cairo ,a monocentric city, is amongst the most densely concentrated cities worldwide. Most trips converge on central Cairo, where there is employment. The New Urban Communities exhibit a polycentric urban village model. New Cairo, 6th of October - and to a lesser extent El-Sheikh Zayed City - have high numbers of job and activity points relative to their populations.

Residents of the Inner and Central areas of the GCR enjoy good levels of Accessibility to jobs. Scores average between 8% (Qalyoubiya Inner) to 35% (Giza Central). Residents of the NUCs in the periphery suffer from very low levels of Accessibility to jobs: From 0.2% (10th of Ramadan) to 6.7% (New Cairo)

In other words: 1.33 million registered NUC residents can only access 65,000 jobs within an hour of travel time using public transport. 19.1 million registered inner and central Cairo residents can access between 517,000 and 2.265 million jobs under the same conditions.

This is mainly due to the high concentration of jobs located within Inner and Central GCR, the rapid reach of the Cairo Metro and the much shorter travel distances, despite high levels of congestion.

6.1.2. Proposed Corridors with the biggest Accessibility Gain

The study arrived at three potential corridors for future infrastructure investments:

- **PPTI H**: The northern section of the Cairo Ring Road
- **PPTI M**: The El-Mehwar Highway connecting the western NUC's with Cairo. (Industrial Zone - El Esaaf)
- **PPTI C**: The (Youssef Abbas - AUC) connecting New Cairo with Nasr City through Road 90, as proposed by the ITDP for a BRT.

Improvements could be implemented on one corridor, or a combination thereof:

Which combination of corridors achieves the highest Accessibility Gain

One Corridor	Two Corridors	Three Corridors
PPTI H: The northern section of the Cairo Ring Road	**PPTI H**: The northern section of the Cairo Ring Road	**PPTI H**: The northern section of the Cairo Ring Road
	PPTI M: The El-Mehwar Highway connecting the western NUC's with Cairo. (Industrial Zone - El Esaaf)	**PPTI M**: The El-Mehwar Highway connecting the western NUC's with Cairo. (Industrial Zone - El Esaaf)
		PPTI C: The (Youssef Abbas - AUC) connecting New Cairo with Nasr City through Road 90, as proposed by the ITDP for a BRT.
Beneficiaries[11]	**Beneficiaries**	**Beneficiaries**
1,027,077	1,315,504	1,401,904

6.1.3. What we learned from the Accessibility Analysis

The ongoing extension of Cairo Metro Line 3 and Line 4 will improve accessibility in central / inner Cairo significantly. The NUCs will not benefit as much.

To improve accessibility in the NUCs, new projects should focus on the most densely populated NUCs (New Cairo in the East and 6th of October and El-Sheikh Zayed on the West). Still, the accessibility gains for PPTI M (El-Mehwar) and PPTI C (Youssef Abbas - AUC) remains low. The total gain over the future baseline scenario are limited. The proposed eastern and western monorail, and the high-speed railway, will also not improve accessibility in the NUC's by a noticeable margin. There are two reasons to explain this disappointing result:

- The travel distances between the population centers within the NUCs and the centers of employment within the GCR are too long
- The travel distances within the NUCs are very long. Commuters need to utilise feeders to reach trunk services. (PPTI's or planned future infrastructure)

Combining feeder services - already operated by the informal sector - with the long travel times of the trunk routes quickly exceeds the acceptable travel time threshold of 60 minutes. High-travel speeds on the trunk routes do not make much of a difference.

Therefore accessibility considerations favor the PPTI H (Northern Rind Road). The areas within its catchment areas are mostly informal housing areas built on formerly agricultural land. They are problematic, with very low levels of pedestrian connectivity due to a complete lack of street layout and design. They are also an opportunity: The population living within the catchment area of the Ring Road is huge. Employment opportunities are in close proximity, but at present not easily accessible.

[11] Estimate of the number of citizens who access an additional 10% of metropolitan GCR jobs due to the PPTI.

Future infrastructure will rapidly increase the multimodal potential of the ring road: Line 1 of the Metro already intersects it at the center; Line 3 is expected to intersect it in the east and provide an intermodal transit hub connecting to the future electric train connecting the new administrative capital and eastern NUCS; and Line 2 is currently going through a feasibility study to assess the possibility of intersecting the Ring Road in the West.

Furthermore, the proposed eastern monorail will benefit strongly from improving accessibility on the northern ring road, providing further future synergies.

A Multimodal Transport Strategy for the GCR

One thing seemed certain: The New Urban Communities in Cairo are well connected by roads but weakly connected by mass transit. New mass transit corridors - enabled by infrastructure investments - would improve accessibility.

This analysis included a first in Egypt: use of extensive urban data, which showed all public transport routes in the NUCs; a full picture of when and where traffic congestion occurs and a spatial understanding of where people live and work. Early on, team members hypothesised which New Urban Communities to benefit the most from infrastructure improvement.

At the same time, we started to compute accessibility and listen to the data. The results are clear: The Northern Ring-Road benefits a disproportionately large number of citizens: 1,027,077 potential beneficiaries access an additional 10% of the metropolitan GCR jobs due to the PPTI. This compares to 409,298 such beneficiaries for improvements on the El-Mehwar highway, and 154,258 such beneficiaries for improvements on the Youssef Abbas - AUC corridor.

6.2. Future Work and Potential Projects

The current project represents a robust initial analysis into the effects of new transit projects in the GCR. The conclusions are robust. However, the computations - particularly for inner and central Cairo, can only be seen as indicative at present due to a limitation of the data. The current data available on public transit routes was comprehensive only in the NUCs and not for Inner and Central GCR. In the near future, data on all formal and informal transit routes for the entire GCR will be available, and enable more reliable computations for inner and central Cairo.

6.2.1. Define potential public transport infrastructure projects & study feasibility

We used “potential public transport infrastructure / intervention” (PPTI) as a way not to presume a preference for any kind of infrastructure over any other. We strongly suggest further study on the possibility of working with the existing public transport supply, formal and informal, to improve service provision and accessibility.

A series of small scale improvements to traffic management, dedicated bus lanes, rationalised stop infrastructure and formal / informal sector integration into a network logic could achieve the same commercial speed - and thus accessibility gains - of new mass transit (i.e. mono-rail, BRT, metro) infrastructure on the PPTI corridors.

Any PPTI Proposal would require an estimation of demand potential demand; of costs (broken down by capital CAPEX and operational OPEX expenditure); and an economic and financial analysis of the best scenario for investment. These can then be compared with the expected benefits - as computed in this study at a strategic level - to be able to arrive at the final conclusion.

The same concepts apply for any investments in Park-and-Ride PnR infrastructure: Future feasibility analysis for PnR should take into account the commensurate PPTI to be implemented, the multi-modal interchange potential and the available land for construction.

PPTI Proposals: The PPTI proposals are inspired by an international experience each, and are meant as a prompt for further discussion, study and choice of the nature of each PPTI.

- Dedicated bus-lanes (formal and informal) and a network of multimodal stations with pedestrian footbridges and ride-hailing drop-off-points on the northern ring road.
- A hybrid public transport system combining formal and informal operators using concessioning, franchising, other regulatory and incentivising mechanisms on the El-Mehwar Highway and the (Youssef Abbas - AUC) proposed BRT ITDP corridor.

Further feasibility studies of the best PPTI investments, including technical implementability, cost, business model, financial sustainability, risk assessment and operational characteristics should be performed.

6.2.2. Study, design and implement a targeted Social Mobility Subsidy Scheme

Targeting subsidies through a mobility subsidy scheme could unlock the required revenues to fund wide-scale service improvements, protect vulnerable user segments, and most sustainably enhance urban mobility for all.

It would allow the system as a whole to tap new resources, as users with a willingness to pay more for a better service increase system-level funding. The better service in turn attracts new users, creating a virtuous cycle. Targeted social mobility subsidies meanwhile protect vulnerable user segments from price increases, and the ongoing removal of fuel subsidies; while simultaneously improving access to the metropolitan level labor market and thus improving social mobility.

To implement such a targeted Social Mobility Subsidy Scheme the first step would be to study and understand the existing fare structure deeply; design a data-driven new fare structure which ensures everybody is better off and the necessary components (regulatory, organisational, legal, financial, technical, business model and marketing) for a successful and sustainable implementation.

6.2.3. Design for walking and cycling

Every trip starts and ends with the commuter walking. Public transit trips are even more dependent on walking to and from stops. (Figure 2). The pedestrian connectivity shows how highways, walls and street design can rapidly deteriorate accessibility by increasing the actual walking distance to seemingly close destinations. The walking experience model shows challenges to exceed simple measures of travel time.

To be successful, any new PPTI or PnR would need to accommodate pedestrian access. To do so, the final design should choose its exact location to maximise access to nearby centers of activity, employment or living. It should also design pedestrian access and implement infrastructure to be as direct as possible, and minimise deviations due to obstacles.

Cycling carries significant potential to increase the potential user base of the PPTI's. Networks would originate at the multimodal stop and continue uninterrupted to centers of housing. Evidence of latent demand point to high potential ridership of cycling lanes, once correctly designed and implemented.

6.3. Concluding remarks on equity in planning

Planning transportation infrastructure in the age of climate change necessitates a shift to multimodal modes of transport, with a shift away from private vehicles and towards modes of mass transit and active travel. This report starts with the user experience in an attempt to acknowledge the challenges of providing mass transit that can match and exceed the travel time benefits of private vehicles.

Planning transportation infrastructure from the perspective of accessibility, as this report aims to do, places the lives and experiences of people at the very center of the pursued objectives: From assessing the multimodal transport experiences at the present, we aim to provide as many citizens with as much access to opportunity as possible.

This approach maximises accessibility, and thus societal benefit. However, it does not identify citizens with the lowest level of accessibility. Providing a minimum level of service to raise everybody above a minimum threshold level of accessibility would be a second, equitable target to pursue.

We operationalise accessibility by focusing on the transport and land use components. In practice, the individual component of accessibility is just as impactful. An equitable PPTI would thus take targeted measures to be usable by citizens of all ages, sexes, socio-economic standing and physical ability.

Planning gender-responsive urban mobility

To achieve equity, PPTI's and recommendations should account for specific needs of gender-, age-, and group-specific interests. Taking the specific needs of women into account allows transport to maximize the employment and income payoffs for citizens, and impact the economy.

To do so, baseline data on gender-differences in the use of transport need to be collected and analysed. A powerful first step lies in administering a passenger satisfaction survey which focuses on understanding women's trip anatomy and user experience, patterns of trip chaining, gender differences in the use of transport modes, time use and identifying potential gender barriers (safety, security, and other).

Service Planning & Policy Formulation and *Project Design & Operational Policies* need to consider gender, and include monitoring, evaluation and re-adjustment of gender-specific components. Gender responsive urban mobility should thus take place at the level of defining and designing the "Potential public transport infrastructure / intervention" (PPTI) itself.

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8. Glossary

Frequency

Frequency is the inverse of headway. A bus service with a headway of 20 minutes has a frequency of 3 buses per hour. It is a measure of how often a particular service operates; higher frequency of operation means less waiting time.

Headway

In transit planning, headway is defined as the time between consecutive services. It is an indicator for the amount of time a person will wait for a particular service. Assuming that the arrival rate of users at a particular stop is uniform, waiting time is half the headway

Informal Transport

Modes of transportation that are demand-driven, operate without fixed schedules or pick-up and drop-off points. The most common mode of informal transport in Cairo is the microbus. Microbus operators have licenses demarcating the routes/neighborhoods that they are allowed to operate on, but no regulations regarding their schedule or stops.

Line

Public Transport Routes with fixed infrastructure, such as a Metro rail link, are referred to as a Line.

Operating Time

It is the time period during which a particular service is available to the public. In Cairo, CTA buses and Rapid Transit operate from early morning until late at night, with service halting around midnight until the early morning hours.

Public Transport

Modes of transportation that are available to the general public and carry groups of people simultaneously. Buses, trams, trains and rapid transit are all considered public transport

Routes

A particular way between two places. Unlike a trip, a route has no directionality.

Service

Service refers to a trip being realized by a mode of transportation with a regular schedule along a particular route with fixed stops. I.e., a public transit route might exist, but have no services operating within a given timeframe.

Skipped stop

Instance, where transit vehicle does not stop to pick-up passenger as it is filled to capacity and no riders expressed a desire to disembark. Passengers then need to wait for one more headway for the next arriving bus. Skipped stops are amongst the strongest disincentives of public transit usage, particularly in the lack of user information.

Terminal Phenomena

Instance, where public transit vehicle departs from original terminal at capacity, resulting in skipped stops along the route. Common to informal modes of transport, who's headways equal the time to fill the vehicle.

Trips

A journey with a specified origin and destination. A trip that originates at point A and terminates at point B is different to one that originates at point B and terminates at point A. These two trips would constitute a route.

9. Appendix

9.1. Appendix A : Study Area and Population

7.1.1. Boundaries and Areas of the GCR

We chose to delineate the detailed study area and geographic scope of the analysis according to the following formula:

- **Central Cairo and Central Giza**, as defined as the urban agglomeration inside the ring road. Only areas that are recognized as urbanized are analyzed. To do so, we rely on data provided by the Atlas of Urban Expansion (Angel, S., 2016), a multi-year global research project which defined urban edges based on remote sensing using satellite imagery.
- **Inner Cairo and Inner Giza**, as defined by the Atlas of Urban Expansion.
- **Outer Cairo, Outer Giza** and all **NUCs** as defined using their administrative boundaries.

Table A1: Choice of areas for the GCR

Area Unit (Governorate or NUC)	Category	Area - CAPMAS Admin Boundary (km2)	Area - Atlas of Urban Expansion (km2)
Cairo	Central	517 km	375 km
Giza	Central	205 km	95 km
Qalyubia	Central	400 km	48 km
Sharqiya	Central	0 km	0 km
Cairo	Inner	446 km	167 km
Giza	Inner	787 km	222 km
Qalyubia	Inner	362 km	182 km
Sharqiya	Inner	102 km	0 km
15th of May City	Inner	18 km	18 km
	Total Area of Cairo	**2837 km**	**1108 km**
10th of Ramadan	Outer	122 km	0 km
6th of October	Outer	207 km	182 km
Badr City	Outer	35 km	0 km
El Sheikh Zayed City	Outer	53 km	45 km
El Shorouk	Outer	60 km	44 km
New Cairo	Outer	203 km	107 km
Obour City	Outer	79 km	51 km
	Total Area of Outer Cairo (NUCs, except 15th May)	**758 km**	**429 km**
	Total Area of the GCR	3595 km	1537 km
	Study Area	**1866 km^2**	

Administrative boundaries include plots of land that are not urbanized. They are thus not necessarily fit for analysis; a good example is the mountainous desert region around Mokattam within Central

Cairo. These have been excluded using the above methodology, to get a detailed and accurate representation of urban areas. Exclusion of un-urbanised and uninhabitable areas enables a more accurate computation of density, and choice of potential destinations in computing accessibility.

A drawback of the Atlas of Urban Expansion is that it is based on 2013 satellite imagery; NUCs have changed significantly since then, and their urbanized area continues to increase. A couple of NUCs are not even included in the Atlas, namely Badr City and 10th of Ramadan City. Therefore, the consultants decided to use the administrative boundaries of the NUCs as the basis for analysis for Outer Cairo. Table 12 compares area sizes as determined by the Atlas of Urban Expansion with the Administrative area sizes, and highlights the geography chosen for the final area of study.

7.1.2. Partitioning the GCR into even-sized area units

To be able to conduct the required accessibility analysis and compute indices such as travel time, the pedestrian connectivity or others, the map of the research area needs to be partitioned into modular regions. The Greater Cairo Region (GCR) consists of 46 Districts, or ”Qism”, which are further divided to 343 “Shiyakha”. However, these administrative boundaries are not spatially contiguous.

We prefer to explore the use of an even-sized grid system to reference areas across the GCR, and looked at existing open-source discrete global grids. We chose the Uber’s H3 Hexagonal system (Brodsky 2018) for a number of reasons:

- It is a publicly available, free, open source implementation.
- It is hierarchical, allowing the flexible movement across resolutions and hierarchical containment; i.e. each hexagon can be subdivided into seven finer hexagons.
- It uses Hexagons, an important design distinction: Hexagons geographically minimize the quantization error introduced when users move through a city and allow an easy approximation of radiuses

All data points would then be bucketed into hexagons, which ultimately form the basis of analysis. For example, we distribute the population over the hexagons and calculate accessibility for each hexagon.

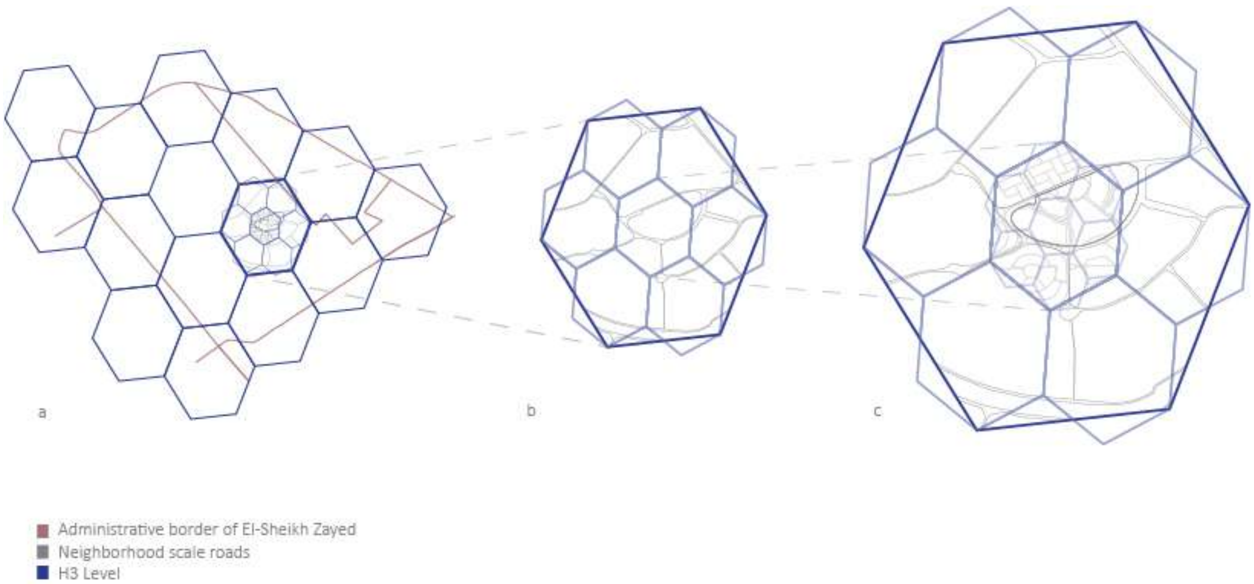

Figure 37: Visualization of different hierarchical resolutions of the H3 hexagonal grid system

7.1.3. Modelling Population of 2018

We acquired population numbers for 2018 from the census of the Central Agency for Public Mobilization and Statistics (CAPMAS), the official agency that conducts statistical and population studies in Egypt. It was manually digitized from pdf to our geospatial database. The lowest granularity we found was at the *Shiyakha* level, an area of varying size with a median area of 5 square km for

Egypt, and 2 square km in the GCR, which had about 640 *shiyakhas*. These population numbers were evenly distributed into smaller units of size which will be used in our analysis.

Before applying the 2018 adjustments, a few issues in the data were resolved. Some *shiyakhas* in the census dataset had zero population in inner and central zones of Giza, Qalyubia and Cairo which was confirmed to be a mistake after a quick satellite image check. A simple method of filling in these areas was used.

First, the shiyakha's population from the previous census report, released in 2015 was used after it was increased by an annual rate equal to the growth rate of Cairo from CAPMAS figures between 2015 and 2018. If the population in 2015 was also zero, like in 6th of October Industrial districts and Smart Village, it remained so. The natural increase used was 1.6% annually. If there was still a population less than ten persons, the median density by zone (inner, central, and outer) per area was used to estimate the population proportional to its area. This method estimated about 220 thousand people to live within nine locations in the GCR dataset. The final GCR population in our dataset was 20.3 million people, in agreement with official reports.

7.2. Appendix B: Deriving a Spatial Employment Model out of the Opportunities Dataset

7.2.1. Building the Opportunities Dataset

Computing accessibility requires a spatially distributed dataset of opportunities, which is geographically referenced. Not only is such a dataset for the GCR not publicly available, but informal employment constitutes an estimated 51% percent of jobs in Egypt (World Bank 2016). The consultant therefore set out to create a proxy for a dataset of the distribution of employment by utilising different publicly available data sources. We relied on a number of geospatial datasets on trip attractors, in the form of places of opportunity, to approximate the spatial distribution of employment.

These sources include the YellowPages directory, the Google Places API, hospital data created by local specialised health consultancy Shamseya, as well as locations of Fawry point-of-sale terminals. The search items were based on the list of greatest trip generators as identified from the code of the Institute of Transport Engineers in the USA. The consultant then modified it for use within the local context. YellowPages and Google both allow searching by categories, and so the categories that matched with the list were shortlisted and each of these categories was examined independently.

To approximate the number of jobs by establishment, the consultant grouped the resulting opportunities dataset points into the categories found in a Labor Force Survey of 2015 acquired from the Economic Research Forum, a research network in Cairo.

7.2.1.1. YellowPages Raw Data

YellowPages is an online directory of businesses in Egypt grouped into different categories. The geocoded address of each business is listed alongside its contact information. The directory is not limited to private companies, but also includes public institutions, schools, hospitals, malls among others.

The website allows you to search for businesses by keyword, category and location. This data was cached as HTML pages using a free parsing software, after which a script was used to export the data in csv format. This allows for the collection of spatially distributed points that are disaggregated by both governorate and category.

7.2.1.2. Google Places Raw Data

The Google Places API was also used to gather information on job locations. The API is a service that returns information about places using HTTP requests. A point grid is layed over the GCR, with the points being 1 km apart. The API returns the latitude, longitude and name of a place using a rankby = distance parameter. This means that the places closest to a point are returned first, with the maximum number of places collected for each point being 20.

Unlike YellowPages, the requests cannot be tailored, but are limited to the categories provided by Google; there are 90 categories of places to choose from. Not all of these categories are relevant to employment, and so they needed to be prioritized based on the extent to which they matched with the list of highest trip generators. A small selection of categories was then queried using the API. The results were then aggregated and the spatially distributed raw data was analyzed.

Table B2: Categories included in opportunities dataset

Category	Source
Factory	Yellow Pages
Ministries & Government Organizations	Yellow Pages
Hospitals	Shamseya
Office	Yellow Pages
Banks	Google Maps
Supermarkets	Yellow Pages
Cinemas & Theaters	Yellow Pages
Clinic	Yellow Pages
Call Center	Yellow Pages
Police	Google Maps
Hotels & Resorts	Yellow Pages
Zoos	Yellow Pages
Clubs	Yellow Pages
Retail	Yellow Pages
Malls (Shopping)	Yellow Pages
Restaurants	Yellow Pages
Caterer	Google Maps
Universities, Colleges & Institutes	Yellow Pages
Schools - International	Yellow Pages
School - Governmental	Yellow Pages
Schools - Languages	Yellow Pages

7.2.1.3. Cleaning the Data

Several procedures were used to clean the raw data obtained:

Removing Duplicates:

- Since the rankby = distance parameter in the Google API does not include a radius to limit results to, many of the places will be retrieved from neighboring points on the grid, and so there will be duplicates. The duplicates are removed by creating a 220m - 250m (0.001 decimal degrees) buffer around each point then using Sequence matcher on python to look for name similarity (IF % similarity in names > 50% THEN count as duplicate and remove). We were careful to include a list of junk words that would not be considered in the similarity calculation; this is important because terms such as 'Bank', 'School' or 'Hospital' are embedded in the names of any facility in their respective categories.
- For some categories, it does not make sense for two facilities to be less than a particular distance from each other. For instance, no two shopping malls can ever be less than 500 meters apart. For the relevant categories, a minimum distance between neighboring facilities

was added, and if any two facilities that violated that distance, one was considered a duplicate and removed.

7.2.1.4. Comparing Datasets

In the cases where the same category was scraped from both YellowPages and Google Places, the processed datasets were compared and the higher-quality dataset was chosen. This was based on visual inspection of the datasets.

7.2.2. Building the Spatial Employment Model

The spatial employment model we created is used as a replacement for employment data. In order to make sure that we do not over or underestimate the actual number of opportunities in the GCR, we started from the employment totals published officially by CAPMAS and did the following

Table B3: Employed Persons in Each Governorate of the GC

Governorate	Total count of jobs
Cairo	2767600
Giza	2112600
Qalyubiya	1589800
Total	6470100 Jobs

1. Categorized every point in our Opportunities dataset according to the industries listed in the LFS - with some points like fawry, not yet categorized
2. Summed the total of points found in each category and each governorate and divided the governorate total employment numbers by these counts. This resulted in the average job per point of each category.
3. The resulting average was compared to similar categories from the NAICS[12] averages of New York City. If found to be too small, we assigned weights from industries whose averages were unrealistically large. This process was repeated iteratively until the averages were in agreement and the unclaimed LFS industries were distributed.

The reason the LFS distributions were slightly inaccurate for our dataset is that the survey comprises all of Egypt while our data set is for the GCR only. For this reason we deviated from LFS industry distributions in the industries whose numbers were inflated for the metropolis like *Agriculture, Forestry, and Fishing, Mining and Quarrying, Manufacturing* and *Other Activities*. Their weights were transferred mainly to Hospital points, whose average number of jobs per location were too low compared to NAICS averages. Otherwise some weight was transferred to universities since lumping them with all levels of educational institutions, as does the LFS, obscured some of the specificity we had from Yellow Pages - like *schools*, *learning centers*, and *universities*. Finally, the *Not Stated* and *Transportation and Storage* weights were assigned to the large set of Fawry points which distributed them according to the spatial distribution that reflects the city's informal or small scale economic activity.

7.2.3. Accounting for Informality within Opportunities and within the Spatial Employment Model

The final opportunities dataset is agnostic of the spectrum of formality and informality found in the Egyptian labor market. As it is entirely based on locations of different opportunities and estimates of their number of Employment Opportunities; the methodology is not affected by the level of reporting of jobs.

The issue differs somewhat with the spatial employment model, which is a model we created used as a replacement for employment data. We normalized the distribution of opportunities on employment

[12] The North American Industry Classification System is a public database which includes the number of employees by industry in the USA. We used NYC numbers when possible because its population density was closest to that of Cairo. When unavailable, we used US-wide averages

levels published by CAPMAS. Thus, the spatial employment model is susceptible to undercounting of informal jobs that are underreported by CAPMAS. However, this still does not affect the final accessibility output.

The Accessibility Analysis is a percent of the total number of jobs, and thus affected by relative distributions rather than absolute numbers. The opportunities dataset, and subsequent normalization on employment figures, are both primarily used to compare spatial distribution. Thus, from a methodological perspective, the final Accessibility Analysis is neither affected positively or negatively by the informal sector that is so prevalent in the Egyptian labor market.

7.3. Appendix C: Corridors and PPTIs

7.3.1. Choosing Corridors

7.3.1.1. Inclusion in past studies

Choosing a shortlist of demand corridors for analysis is a consequential step: The final recommended corridors can only be part of the shortlist that is analysed. The term corridor is primarily used to determine the set of physical routes under study. It is therefore necessary to create a clear distinction between corridors and the routes of any potential intervention (as outlined in Table 5). To ensure the optimal choice of corridors, we narrowed down the main road arteries based on inclusion in past studies, coverage, geographic specificities and transit service availability.

The first step in this process is to create a comprehensive preliminary shortlist of corridors that we can then analyze. We started by mapping all corridors identified in previous transportation related studies in the GCR, and mapped the WB Traffic Study (2014) and COWI CTA Study (2016) on GIS. We then made modifications to the corridor routing, so that they originated and ended at existing public transport terminals. Then, we categorized all shortlisted corridors into three geographic classifications based on origin and destination, namely:

- **(NUC-NUC)** New Urban Community - New Urban Community
- **(NUC-CAI)** New Urban Community - Inner-City Cairo
- **(CAI-CAI)** Inner-City Cairo - Inner-City Cairo

This leads to 17 corridors.

7.3.1.2. Coverage provided by Corridors

The second step was to ensure that all NUCs are served by at least one corridor. The NUC of 15th May was not served by any corridors and so an 18th corridor was extended to it.

7.3.1.3. Transit service availability and geographic specificities

The third step is to ensure that all areas with significant transit service or demand are covered. Present transit service, as provided by the Digital Cairo Bus GIS/GTFS 2018 dataset previously collected by Transport for Cairo was examined to determine if there were any major corridors left between Central Cairo and the NUCs that we had not covered.

Bus routes operated by the CTA were specifically examined, as corridors that are not covered by the CTA are unlikely to have the infrastructural capacity for a BRT route. From this inspection, we found that a significant number of routes pass by Sadat Axis in the First Settlement and so we extended Al Methaq corridor so that it covers that axis.

Future expected transit service was then examined, to ensure that any corridors that might be serviced in the future are included in the present and future accessibility analysis. Accordingly, we also added the BRT corridor currently being studied by ITDP in the Western area of the GCR as it includes segments that don't overlap with any of the corridors from the above-mentioned studies.

The 19 shortlisted corridors are in Table 18 below.

Table C4: List of all corridors included within the study

Corridor Name	Corridor Route	Length (km)	Category	NDCs Served
Ring Road North	Zahraa Madinet Nasr - Masaken Othman	95.2	NDC-NDC	NC;SQ;6O
Cairo Ismailia Desert Road / El Qubba	10th of Ramadan City - El Qubba Bridge	63.2	NDC-CAI	AR;OB;SQ
Ring Road South	Zahraa Madinet Nasr - Smart Village	57.9	NDC-NDC	SZ;6O;NC
Cairo-Suez Desert Road / Ibn El Hakam Square	Badr City - Ibn El Hakam Square	50.9	NDC-CAI	NC;SQ;BD
ITDP_6th October City (2)	Giza Square - Industrial Zone	50.3	NDC-CAI	6O
26th of July / 15th of May	Industrial Zone - El Esaaf	45.2	NDC-CAI	SZ;6O
Autostrad Corridor	Kilo 4.5 Bridge - 15th of May City	42.9	NDC-CAI	5M
El Corniche- East / El-Matareya Square	El Matareya Square - Maadi Corniche	31.6	CAI-CAI	None
AUC (New Cairo) - Abbassiya	AUC Campus - Abbasiya Square	31.3	NDC-CAI	NC
ITDP_New Cairo	Youssef Abbas - AUC	31.3	NDC-CAI	NC
Cairo-Suez Desert Road / El Qalaa	Zahraa Madinet Nasr - Al Sayeda Aisha	25.4	NDC-CAI	NC
Rod El Farag / El Remaya	Mazalat - Remaya Square	24.0	CAI-CAI	None
Autostrad-Thawra Intersection/Giza Sqr	Kilo 4.5 Bridge - Giza Square	21.3	CAI-CAI	None
El Orouba / 6th of October Bridge	Cairo International Airport - El Batal Ahmed Abd EL Aziz	20.8	CAI-CAI	None
Cairo-Alex Agr. Road / El Qubba	Upstream Ring Road Interchange - EL Qubba Bridge Military Hospital	19.6	CAI-CAI	None
Al Methaq Corridor	Al Khalifa Al Zaher - Lotus	9.5	NDC-CAI	NC
Port Said Corridor	Church of the Angel Michael Street - Sayeda Zeinab Square	8.9	CAI-CAI	None
Gesr El Suez Corridor	Alf Maskan Square - Abbasiya Square	8.7	CAI-CAI	None
Mo'assaset Al Zakah Corridor	Ring Road - El Tawfikiya Canal Street	7.6	CAI-CAI	None

7.3.2. Deriving PPTIs from Shortlisted Corridors

An important distinction needs to be made between the corridors we identified and the potential public transport interventions (PPTIs) we recommend

Table C5: Definition of corridor, segment and PPTI

Corridor	Main demand linear itinerary along existing infrastructure, to be eventually used by a *potential public transport infrastructure (PPTI).* Each *corridor* consists of multiple *segments*.
Segment	Segments form the micro-unit of analysis; we compute travel time and congestion per segment. Chaining segments together creates a *corridor*. The entire length of each *corridor* is split into *segments* to create an OD matrix between connecting segments. Segments are delineated according to multiple criteria: 1. Real Transit stops mapped as part of Digital Cairo Bus GIS/GTFS 2018 were used as delineators. 2. Segments that did not overlap were delineated into smaller units ideal for analysis, generally by using intersection as delineators.
PPTI route	The transit route to be eventually used by the *potential public transport infrastructure* (PPTI), possibly a BRT. Identifying and comparing PPTIs is the main objective. The PPTI could be the sum of (i) an NDC-CAI or NDC-NDC corridor and (ii) a CAI-CAI corridor. Special consideration will be given to any present and future rail system along the itinerary. The following statements clarify the relationship between PPTI routes and corridors: ● A PPTI can be equal to an entire corridor ● A PPTI can also be a part of a corridor (Not the full length) ● A PPTI can be composed by chaining together segments from multiple corridors We will start with one PPTI per corridor and then, through further manual analysis based on public transport best practices as outlined by Walker (2012), identify the final list of PPTIs to be analyzed. This level of analysis will include: ● Infrastructure design: As defined by directness of the route, as opposed to being circuitous or deviating ● Barriers and Chokepoints: A barrier is anything that obstructs direct travel (e.g. a river). Chokepoints are the limited points at which you can cross a barrier. Chokepoints are a problem for cars but are opportunities for potential public transport as many lines merge onto them

7.3.3. Travel Time on Corridor Segments

The quality of the network is best understood through the efficiency with which a vehicle can travel on it. This efficiency can be best captured using three indicators: Congestion, Average Speed, and Commuting Time Predictability.

To do so, we need to collect travel time and travel time deviations for each corridor, and combine them into a travel time matrix. The entire length of each corridor is split into segments. First, we used actual transit stops as identified in the Digital Cairo Bus GIS/GTFS 2018 database to delineate the segments. These stops were only created for trips that the consultant had previously mapped as part of Digital Cairo Bus GIS/GTFS 2018, and they overlapped with the majority of the shortlisted corridor sections. The sections that did not overlap were those that extended to some of the NUCs such as Badr and 10th of Ramadan. Stops were added along these sections sections to create segments. Additional Stops were added at the entrances and estis of each NUC, and at major intersections along the corridor.

7.3.3.1. Traffic Data

The segments form the Origin-Destination pairs. An OD matrix was then created to collect traffic data. A script was programmed to tap into the dynamically updated transportation network data maintained by Google through the publicly available API and obtain a reliable estimate of OD travel time matrix. We obtained live travel time on each segment in nine bi-hourly increments between 5:00 am and 21:00 pm. This was done over a two month period, and included four weekdays and two weekend days (Saturday).

The live data points allow us to interpolate traffic data for the entire time period between 5:00 am to 21:00 pm and, in doing so, calculate the travel time variability and estimate average travel speeds for each segment.

Table 6 summarises the data points collected to date. The slight variability of Observations per Day is due to the inability of the API to return a reliable estimate. Such missing values are systematically removed from any statistical computations or visualisation, and thus do not significantly affect the final outcome.

Table C6: Summary table of the Travel Time Data Collection to date

Summary of the Travel Time Data Collection (11-03-2019)					
Month	Day	weekday	Observations per Day	Unique Segments observed	Time_slots observed
January	14	Mon	7912	854	9
January	19	Sat	7878	854	9
January	20	Sun	7877	854	9
January	22	Tue	7845	854	9
March	5	Tue	8106	868	9
March	9	Sat	7895	868	9
			47513	Observations	

7.3.4. Ride-Hailing Analysis Tables and Figures

Table C7 visualise the geographic distribution of trips over the given city-pairs and over time. Every cell represents the total number of trips for each city pair combination (row) starting within that time period (column) normalised to the number of trips witnessed in the most active city-pair (Within GCR Central/Inner) at the most active time-period (6pm-9pm). The purpose of Table C7 is to get an understanding of the relative importance of city-pairs in relation to one another, while distinguishing between different times of the day. Colours are used to distinguish high-values from low, turning the table into a heatmap.

Table C8 visualises the geographic distribution of trips over the given city-pairs normalised by day.

Table C7: Distribution as proportions of the peak period for the most active City Pair, within the GCR

Distribution normalised for the peak period for the most active City Pair							
City Pair	0am-6am	6am-9am	9am-12pm	12pm-3pm	3pm-6pm	6pm-9pm	9pm-12am
Between eastern NUCs	0.2%	0.3%	0.7%	0.7%	0.8%	0.6%	0.5%
Between western NUCs	0.9%	0.9%	1.8%	2.3%	3.1%	3.2%	2.3%
Cairo & Qalyubia - Eastern NUCs	2.4%	3.3%	5.6%	5.8%	7.0%	6.6%	5.0%
Cairo & Qalyubia - Western NUCs	0.6%	0.5%	0.9%	1.3%	1.4%	1.3%	1.1%
Cross GCR NUC travel	0.1%	0.1%	0.2%	0.3%	0.3%	0.2%	0.2%
Eastern NUCs - Cairo & Qalyubia	2.6%	2.8%	4.9%	6.0%	8.0%	7.2%	5.6%
Eastern NUCs - Giza	0.4%	0.3%	0.6%	0.6%	0.7%	0.7%	0.7%
Giza - Eastern NUCs	0.3%	0.4%	0.6%	0.7%	0.7%	0.6%	0.4%
Giza - Western NUCs	1.0%	1.1%	1.7%	2.1%	2.7%	2.5%	1.6%
Western NUCs - Cairo & Qalyubia	0.7%	0.9%	1.2%	1.2%	1.3%	1.3%	1.1%
Western NUCs - Giza	1.3%	1.0%	1.7%	1.9%	2.3%	2.5%	2.4%
Within GCR Central/Inner	48.0%	41.8%	65.6%	78.5%	96.6%	100.0%	80.5%
Within NUC	7.5%	8.6%	15.7%	20.0%	24.9%	23.8%	17.3%

Table C8: Distribution of ride-hailing trips over hours of the day

Table 11: Distribution of ride-hailing trips over hours of the day								
City Pair	0am-6am	6am-9am	9am-12pm	12pm-3pm	3pm-6pm	6pm-9pm	9pm-12am	Whole day
Between eastern NUCs	5.0%	9.0%	19.2%	19.3%	20.5%	15.2%	11.8%	**100%**
Between western NUCs	6.4%	6.2%	12.4%	15.8%	21.4%	21.8%	15.9%	**100%**
Cairo & Qalyubia - Eastern NUCs	6.8%	9.1%	15.7%	16.1%	19.6%	18.6%	14.0%	**100%**
Cairo & Qalyubia - Western NUCs	8.8%	7.7%	13.3%	17.7%	19.4%	18.0%	15.0%	**100%**
Cross GCR NUC travel	6.8%	9.9%	15.7%	17.6%	19.4%	16.8%	13.7%	**100%**
Eastern NUCs - Cairo & Qalyubia	6.9%	7.6%	13.3%	16.2%	21.5%	19.3%	15.1%	**100%**
Eastern NUCs - Giza	10.0%	8.4%	14.0%	14.8%	18.2%	17.5%	17.1%	**100%**
Giza - Eastern NUCs	6.6%	11.6%	16.4%	18.0%	19.6%	16.8%	11.0%	**100%**
Giza - Western NUCs	7.5%	8.8%	13.3%	16.4%	21.5%	19.5%	12.9%	**100%**
Western NUCs - Cairo & Qalyubia	9.0%	12.0%	15.7%	15.4%	16.8%	17.3%	13.9%	**100%**
Western NUCs - Giza	10.1%	7.3%	13.0%	14.7%	17.9%	18.8%	18.3%	**100%**
Within GCR Central/Inner	9.4%	8.2%	12.8%	15.4%	18.9%	19.6%	15.8%	**100%**
Within NUC	6.4%	7.3%	13.3%	17.0%	21.1%	20.2%	14.7%	**100%**

7.3.5. Modelling PPTIs

We model the PPTI by defining (a) a set of stops along the corridor respecting average distances within populated areas, and setting (b) travel time to equal the commercial speed. Based on these assumed stops and travel times, we created dummy GTFS files: A simulated PPTI X Scenario GIS/GTFS dataset. This dataset is a composite of the simulated PPTI data, and the actual baseline dataset, meaning that travel time along the PPTI route is set at the commercial speed, while travel time across the rest of the network is obtained through the Google API.

7.3.6. Computing the effect of the PPTI on Accessibility

We then redo the entire Accessibility Analysis as defined in Appendix F. Following the same steps: TfC Travel Time Matrix (PT, PPTI X scenario) for travel using public transport between every possible OD-pair; followed by a single point analysis, a regional analysis for areas affected by the corridor, and a computation of an "Accessibility Score (PT, PPTI X scenario)". The final output is the corridor specific Accessibility Indicator for the metropolis.

This computation is redone multiple times: Once for each PPTI route, yielding a TfC Travel Time Matrix (PT, PPTI X scenario) and Accessibility Score (PT, PPTI X scenario) for each one. The final step is to compare the baseline dataset with the scenario dataset, yielding the expected accessibility gain by PPTI; in effect creating an Accessibility Gain (PT, All PPTIs) dataset.

7.3.7. Comparing different PPTI and ranking shortlisted corridors.

In the absence of a clearly defined set of categories with which to judge the suitability of the candidate corridors and PPTIs, the consultant has made use of the variety of expertise found in the team dedicated to this project in the form of a mini-Delphi process. The Delphi method was created in the 1940s in the US to "obtain the most reliable opinion of a group of experts" (Dalkey and Helmer 1963) by soliciting their opinions or forecasts in a matter and revealing to them the results of the group and subsequently repeating the process until a consensus is reached. Our application, termed the mini-Delphi, was conducted in one sitting where the results were shared immediately and the consensus reached without anonymity. The members of the team were asked to rank the factors affecting the success of a PPTI from most influential to least, and the ranks were summed to give the highest scores to those factors ranked highly by the group, and vice versa. From 8 separate factors, 4 were settled upon to comprise our ranking methodology. They are:

1. Improved accessibility to jobs
2. Dispersal of Investment to cover distinct parts of the city (Eastern, Western, etc.)
3. Prioritize the improvement of access to areas with already low access
4. Equitable distribution of recommendations to areas with low income

The final recommendations of corridors H, M, and C address all of the factors identified and listed above. By applying the recommendation of Martens (2017) to value the improvement of accessibility in those areas that start at a lower level of access, we target NUCs on the West and East by corridors M and C. However, the areas at the ends of those corridors have a wealthier resident population compared to the neighborhoods in Giza and Qalubiya near the ring road, as measured by real estate prices from a data set acquired online from Aqarmap.com (a local brokerage website). For this reason, Corridor H targets the improvement of accessibility for those areas that are densely populated formerly agricultural informal settlements. This method ensured the equitable distribution of the potential gains of the PPTIs on a wide variety of citizens.

The newly created Accessibility Gain (PT, All PPTIs) now fits in a larger framework of improved access to the transportation network by more people.

Table C9. Accessibility Analysis results for 2 corridor combinations for NUCs (Base Scenario in Bold)

City	B	HM	HL	HD	HC	HI	HJ	MD	MC
10th of Ramadan	**0.15**	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
15th of May City	**1.49**	1.49	1.49	1.49	1.49	1.49	1.66	1.49	1.49
6th of October	**3.86**	4.06	3.95	3.87	3.86	3.86	3.86	4.05	4.05
Badr City	**0.22**	0.22	0.22	0.22	0.22	0.25	0.22	0.22	0.22
El Sheikh Zayed City	**1.79**	2.22	1.79	1.79	1.79	1.79	1.79	2.20	2.20
El Shorouk	**0.57**	0.57	0.57	0.57	0.57	0.58	0.57	0.57	0.57
New Cairo	**5.87**	5.92	5.93	6.78	6.30	5.94	5.93	6.73	6.25
Obour City	**3.11**	3.11	3.11	3.11	3.11	3.11	3.11	3.11	3.11

Metropolitan	**24.49**	26.54	26.38	26.44	26.48	26.35	26.44	24.92	24.96

Table C10. Accessibility Analysis results for 2 corridor combinations for non-NUC zones of the GCR (Base Scenario in Bold)

City	B	HM	HL	HD	HC	HI	HJ	MD	MC
Cairo_Inner	**18.58**	18.68	18.73	18.86	18.71	18.68	19.11	18.76	18.60
Cairo_Outer	**0.51**	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51
Cairo_central	**33.54**	33.79	33.79	33.80	34.25	33.88	34.01	33.55	34.00
Giza_Inner	**12.19**	15.98	15.29	15.28	15.13	15.13	15.13	13.52	13.37
Giza_Outer	**13.24**	13.51	15.25	13.53	13.51	13.51	13.51	13.26	13.24
Giza_central	**35.15**	39.40	38.95	39.19	38.81	38.82	38.82	36.31	35.94
Qalyoubia_Inner	**7.85**	11.45	11.45	11.45	11.45	11.46	11.45	7.85	7.85
Qalyoubia_central	**27.58**	31.99	31.99	31.99	31.99	32.03	31.99	27.58	27.58
Metropolitan	**24.49**	26.54	26.38	26.44	26.48	26.35	26.44	24.92	24.96

Table C11. Accessibility Analysis results for 3 corridor combinations for NUCs (Base Scenario in Bold)

City	B	HLC	HMC	HLI	HMI	HLG	HMG	HLK	HMK
10th of Ramadan	**0.15**	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
15th of May City	**1.49**	1.49	1.49	1.49	1.49	1.49	1.49	1.49	1.49
6th of October	**3.86**	3.95	4.06	3.95	4.06	3.95	4.06	3.95	4.06
Badr City	**0.22**	0.22	0.22	0.25	0.25	0.22	0.22	0.22	0.22
El Sheikh Zayed City	**1.79**	1.79	2.22	1.79	2.22	1.79	2.22	1.79	2.22
El Shorouk	**0.57**	0.57	0.57	0.58	0.58	0.57	0.57	0.57	0.57
New Cairo	**5.87**	6.31	6.30	5.95	5.94	6.63	6.63	6.42	6.41
Obour City	**3.11**	3.11	3.11	3.11	3.11	3.11	3.11	3.11	3.11
Metropolitan	**24.49**	26.55	26.70	26.42	26.58	26.43	26.59	26.46	26.61

Table C12. Accessibility Analysis results for 3 corridor combinations for non-NUC zones of the GCR (Base Scenario in Bold)

City	B	HLC	HMC	HLI	HMI	HLG	HMG	HLK	HMK
Cairo_Inner	**18.58**	18.76	18.71	18.73	18.68	18.74	18.69	18.74	18.68
Cairo_Outer	**0.51**	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51
Cairo_central	**33.54**	34.25	34.25	33.89	33.88	33.90	33.89	33.98	33.98
Giza_Inner	**12.19**	15.29	15.98	15.29	15.98	15.29	15.98	15.29	15.98
Giza_Outer	**13.24**	15.25	13.51	15.25	13.51	15.25	13.51	15.25	13.51
Giza_central	**35.15**	38.95	39.40	38.96	39.40	38.96	39.40	38.95	39.40
Qalyoubia_Inner	**7.85**	11.45	11.45	11.46	11.46	11.45	11.45	11.45	11.45
Qalyoubia_central	**27.58**	31.99	31.99	32.03	32.03	31.99	31.99	31.99	31.99

Metropolitan	**24.49**	26.55	26.70	26.42	26.58	26.43	26.59	26.46	26.61

7.4. Appendix D: Headway Data Collection

In order for the accessibility analysis to yield results that are an accurate representation of reality, the GTFS feeds must have accurate operational data for all trips. It is important to note that the public transport routes of the GCR were mapped in two separate projects: Digital Cairo Bus GTFS 2018 (Phase 1) was focused exclusively on mapping trips serving the NUCs, while World Bank Inner Cairo 2019 was focused on mapping Inner and Central Cairo.

In World Bank Inner Cairo 2019, we collected temporal data to estimate headways. The data collected in Digital Cairo Bus GTFS 2018 (Phase 1) was limited to routes and fares and so a small data collection effort was carried out to collect headways for these trips. Given the time and budget constraints of this project, we are unable to collect headway data for all trips in Digital Cairo Bus GTFS 2018 (Phase 1). We therefore limit the headway data collection to trips that are most important to this study.

7.4.1. Headway Calculation for World Bank Inner Cairo 2019

Information on operating schedules does not exist for either formal buses or informal transit. We therefore need to make approximations for operating schedules and headway.

This was done in two seperate ways.

7.4.1.1. Using No. of Buses

The first (preferred method) was to calculate the headway based on the number of buses that operate on that route. Field researchers managed to obtain these figures for some of the CTA routes by asking either the terminal operator or a bus driver[13]. If this information is available for a particular route, we calculate the trip headway using the following equation:

$$Dwell\ Time\ = Depart\ Time\ -\ Onboard\ Time$$

$$Headway\ = [\ ((Trip\ Duration\ +\ Dwell\ Time)\ * 2)\ /\ No.of\ Buses\ ]$$

The trip duration and dwell time are added together to calculate the duration of one trip. This is multiplied by two to get the total duration for a complete route, giving us the estimated headway if only one bus was operating on the route. Dividing by the number of buses gives us a good estimate of the headway.

We are able to calculate the dwell time because the field researchers record their waiting time for every trip using RouteObserver. Timestamps for the on-boarding time and the trip depart time are also recorded.

7.4.1.2. Using Waiting Time

For routes where we do not have information on the number of buses, we use the total waiting time, onboard time and depart time to estimate headway. Total Waiting Time is the sum of the time spent at the terminal waiting for a bus to arrive and the time spent onboard the bus waiting to depart. The headway for the trip is estimated using the following equation:

$$Total\ Waiting\ Time\ =\ (Depart\ Time\ -\ Onboard\ Time)\ +\ Waiting\ Time$$

$$Headway\ = 2\ *\ Total\ Waiting\ Time$$

The relationship between Total Waiting Time and Headway is valid because arrival at a terminal is random and uniformly distributed. Passengers therefore spend, on average, half of the headway waiting at the terminal.

[13] We have this figure for 26 CTA routes. Asking questions puts field researchers at risk, so they were instructed not to ask this question directly but to report it back if it came up naturally in conversation

7.4.2. Headway Calculation for Digital Cairo Bus GTFS 2018

The best location to collect headway data for a trip is from its starting point. All trips in our database start and end at particular locations. These locations are normally in close proximity to one another and tend to form clusters. These clusters were combined into points on a processed stop layer and are referred to as terminals. They do not necessarily have to be physical structures designated by the government; they can be squares, street intersections or locations where several transit vehicles are parked along a street. This data was collected during Digital Cairo, and Digital Cairo Bus GIS 2018 (Phase 1) includes 119 terminals across the GCR.

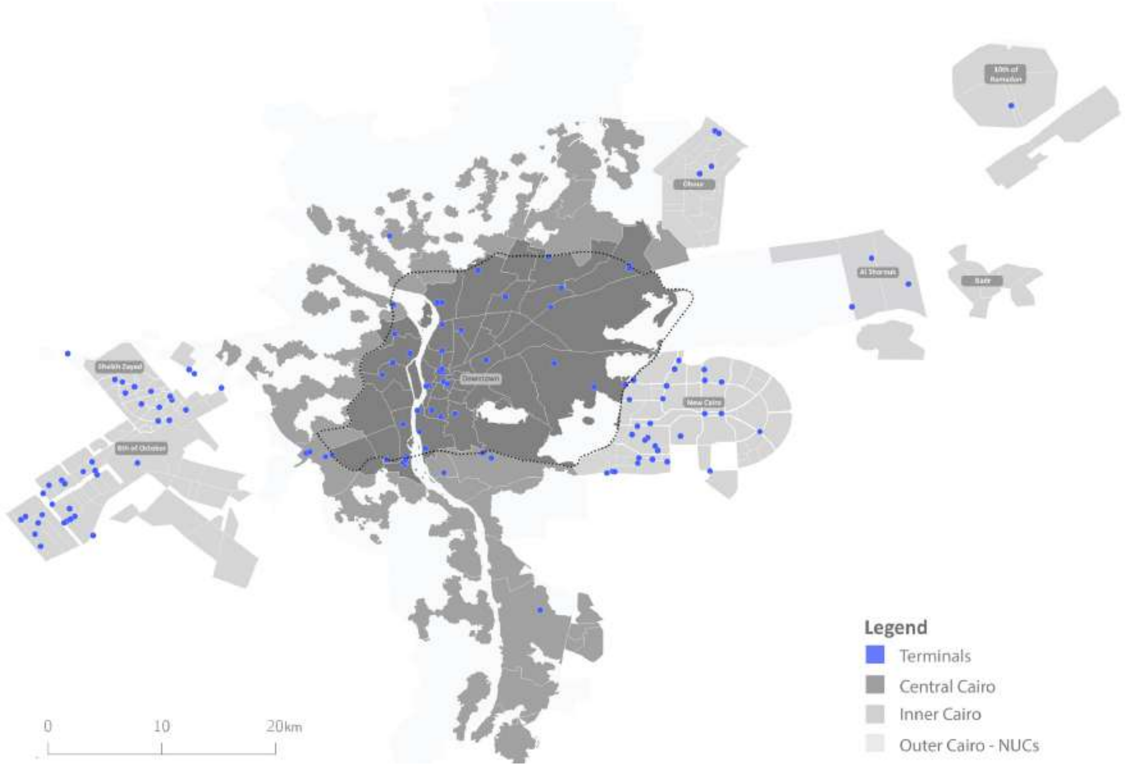

Figure 33: Terminals across the GCR - Data from "Digital Cairo Bus GIS 2018 (Phase 1)"

The first step in identifying which trips to collect data on is to filter out the terminals that were least relevant to our study. A preliminary shortlist of terminals was carried out to identify where data collection would be most useful for the study. Terminals that passed either of the following criteria were shortlisted.

Table D13: Criteria for Shortlisting Terminals (Step 1)

Criteria	Computation Method
Terminal falls within range of shortlisted corridor	Create a buffer of 200m for the shortlisted corridors on the GIS and then single out the terminals that fall within range of each corridor buffer
Terminal has transit trips originating from it that fall within range of shortlisted corridor	Identify origin of trips that intersect with any shortlisted corridor

94 terminals passed the criteria. These terminals were ranked in terms of importance to the study according to the methodology outlined in the section below

In order to manage our limited resources effectively, the team had to identify which terminals were key to the analysis. A system was developed to rank the terminals based on their size as well as their relationship to the shortlisted corridors. The following table explains the criteria and methodology used for ranking the terminals. It includes the weights for each indicator, which were selected based on the consultant's judgement of the relative importance of each indicator.

Table D14: Criteria for Terminal Ranking (Step 2)

#	Criteria	Computation method	Unit	Example	Why
1	Coverage of transit trips that leave from terminals **Weight** 50%	1) Create a network of all transit trips originating out of terminal x 2) Create a 500 m buffer around this network 3a) Compute (Area of network for each terminal in m2 / Total Area of GCR in m2) 3b) Compute (Population within catchment area / Total population of GCR)	INDEX 3a) 30% weight 3b) 70% weight	For Terminal **Hyper One** 3a) 0.20 3b) 0.07 INDEX = 0.2*0.3 + 0.07*0.7 = 0.11	Proxy Indicator for Terminal Importance.
2	Terminal Pedestrian Connectivity **Weight** 30%	1) Determine centroids of each NUC + main transport hubs in inner-city Cairo 2) Compute travel time from chosen terminal to each destination 3) Compute aerial distance from chosen terminal to each destination 4) Compute (total distances / total times)	km/h (higher is better)		Indicator for Efficiency of terminal

3	Terminal Relationship to Shortlisted Corridors **Weight** 20%	1) Check for trips (Criteria #1 Buffer) that intersect with shortlisted corridors 2) Compute: (no. of trips originating from terminal x intersecting with Shortlisted corridors)/ (total no. of routes from all shortlisted terminals intersecting with potential Bus corridors)	Ratio	- Hyper One Terminal = 7 trips intersect with shortlisted corridors - All Terminals = 40 trips intersect with shortlisted corridors - Ratio = 7/40 = 0.175	Indicator for Potential on-corridor competition

Table D15: Criteria for Terminal Ranking (Step 3)

HYPER ONE Terminal	
Criteria	**Rank**
Coverage of cars that leave from terminals	5
Terminal Pedestrian Connectivity	7
Terminal Relationship to Shortlisted Corridors	12
WEIGHTED AVERAGE	(5*50%) + (7*30%) + (13*20%) = **7.2**

The terminals were then ranked according to their 'WEIGHTED AVERAGE' values, with the highest ranking terminals being those with the highest value.

7.4.2.1. Available Resources

A calculation was done to determine the scope of data collection given the available resources. It was agreed that six field researchers would be hired for twenty working days for the field data collection. The research team will have the capacity to collect headway data for an estimated 160 unique trips. The data collection period began on December 20th 2018 and will continue until January 10th 2019.

7.4.2.2. Identification of Trips for Data Collection

After ranking the terminals according to the above criteria, and calculating the data collection capacity, the consultant identified the unique trips originating from each terminal that were most relevant to the study, based on the Digital Cairo Bus GTFS 2018 (Phase 1) dataset. All trips intersecting with a 200 m buffer around the shortlisted corridors were shortlisted. This produced 278 unique trips (out of a total of 365 trips) with an average intersection of 18 km. As this was above the calculated capacity of 160 trips, a second filter was needed. A second iteration was done to filter out trips that intersected for less than the calculated average distance, leaving 145 unique trips. These trips were ranked according to the importance of the terminal they originated from, and then according to their length. It was decided that for any terminal where data collection will occur, data on a minimum of two trips will be gathered. For terminals that had only one trip fitting the above-mentioned criteria, a second trip from each terminal was added to the shortlist. This left us with 157 trips. The table below shows the breakdown of the trips that data will be collected on:

Table D16: Vehicle types for trips where primary data collection is planned

Code	Type	Number	% of Total
P_O_14	14 seater informal transport microbus	87	55.41%
CTA	CTA bus	35	22.29%
CTA_M	Minibus licensed by CTA	17	10.83%
COOP	Cooperative informal transport 29 seater	13	8.28%
P_B_8	informal transport 8 seater Suzuki Chevrolet or DMF	5	3.18%
	SUM	**157**	

7.4.2.3. Mobile Application (Headway)

A mobile application was developed by the consultant to assist in the fieldwork. The purpose of the application is to generate csv files of trip arrival and departure times. The application asks users to enter a USER ID, Terminal ID, and Trip ID.

It then creates a tab for the user with the Trip ID, giving them two options: Arrival and Departure. The user is then able to click on Arrival when the Bus with the relevant Trip ID arrives then Departure when it leaves the terminal. When the user is finished recording, they can save the information and upload it from the phone to a Google Drive, where it can be accessed automatically by the Field Research Manager. For each Trip recorded on a particular day, the output is a csv file with the columns: Sequence - User ID - Terminal ID - Trip ID - Arrival Time - Departure Time. A sequence of Arrival and Departure times is made available for the calculation of average headway and dwell time.

7.4.2.4. Data Collection Progress

As of the submission date of this report, the data collection has wrapped up. The first and second weeks were based in Western and Eastern Cairo respectively, while the third week was based in Central/Inner Cairo.

The field researchers did not just record headway but also report on the fare of each trip, enabling us to calculate the cost of any multi-modal trip. Table 13 below shows sample data for the CTA bus going from Al Souq Al Qadeem in 6th of October City to Abd El Moneim Riad in Downtown Cairo.

Table D17: Three different instances of arrival and departure times for CTA 1013 (Al Souq Al Qadeem - Abd El Moneim Riad)

terminal_name	trip_id	fare (EGP)	arrival_time	departure_time
Al Souq Al Qadeem	CTA_1013_R	5	19/01/2019 09:27:54 AM +00:00	19/01/2019 09:34:04 AM +00:00
Al Souq Al Qadeem	CTA_1013_R	5	19/01/2019 09:35:57 AM +00:00	19/01/2019 09:45:14 AM +00:00
Al Souq Al Qadeem	CTA_1013_R	5	19/01/2019 09:45:36 AM +00:00	19/01/2019 09:54:50 AM +00:00
Al Souq Al Qadeem	CTA_1013_R	5	19/01/2019 09:55:07 AM +00:00	19/01/2019 10:08:03 AM +00:00
Al Souq Al Qadeem	CTA_1013_R	5	19/01/2019 10:08:17 AM +00:00	19/01/2019 10:16:34 AM +00:00
Al Souq Al Qadeem	CTA_1013_R	5	20/01/2019 03:11:08 PM +00:00	20/01/2019 03:12:10 PM +00:00
Al Souq Al Qadeem	CTA_1013_R	5	20/01/2019 03:26:58 PM +00:00	20/01/2019 03:27:47 PM +00:00

Al Souq Al Qadeem	CTA_1013_R	5	21/01/2019 12:11:29 PM +00:00	21/01/2019 12:15:03 PM +00:00
Al Souq Al Qadeem	CTA_1013_R	5	21/01/2019 12:20:03 PM +00:00	21/01/2019 12:28:26 PM +00:00
Al Souq Al Qadeem	CTA_1013_R	5	21/01/2019 12:28:28 PM +00:00	21/01/2019 12:40:09 PM +00:00

For each trip, regardless of mode, 5 data collection instances are done at different times in the day, with each instance being equal to a 45 minute observation slot at the terminal. The number of trips observed, broken down by mode and terminal of origin, is shown in Table 14 below.

Table D18: Data Collection Progress as of 15 February, 2019

Area	Terminals	CTA Trips	Microbus Trips	Private Sector Bus Trips	Status
Western Cairo	El Hossary	0	11	0	Complete
	Laylat Al Qadr	1	6	0	Complete
	District 6	1	6	0	Complete
	Al Souk Al Qadeem	2	1	0	Complete
	Hyper	0	8	2	Complete
	Badr	2	0	0	Complete
	Mehwar Desert Rd	0	2	0	Complete
	Dandy Mall	0	2	0	Complete
	Haram Marioteyya	0	4	0	Complete
	Total	**6**	**40**	**2**	**Complete**
Eastern Cairo	Obour	2	0	0	Complete
	Al Shorouq	2	0	0	Complete
	Al Shorouq Academy (Dorra)	0	2	0	Complete
	Al Shorouq Water Station	0	1	0	Complete
	Alf Maskan	0	2	0	Complete
	10th of Ramadan Station	0	2	2	Complete
	New Marg	1	3	2	Complete
	First Settlement	10	0	0	Complete
	Third Settlement	4	0	0	Complete
	Bonook	0	5	1	Complete

	Mahkama	0	2	2	Complete
	Gas	0	2	0	Complete
	FUE	0	1	1	Complete
	Omaal Square	0	2	0	Complete
	Higher Technological Institute	0	1	1	Complete
	AUC	1	0	0	Complete
	Total	**20**	**23**	**9**	**Complete**
Central/Inner Cairo	Lebanon Square	0	2	0	Complete
	Moneeb	1	4	0	Complete
	Giza Square	1	3	0	Complete
	Helwan	0	2	0	Complete
	Ramses	0	5	0	Complete
	Attaba	2	0	0	Complete
	Abd Al Moneim Riad	7	1	0	Complete
	Imbaba	1	1	0	Complete
	Al Sayeda Aisha	0	2	0	Complete
	Ahmed Helmy	2	0	0	Complete
	Al Moassasa	2	4	0	Complete
	Isko	2	0	0	Complete
	Dawaran Shubra	2	0	0	Complete
	Abbaseya	1	0	0	Complete
	Al Zawya Al Hamra	2	0	0	Complete
	Total	**23**	**24**	**0**	**Complete**
TOTAL		49	87	11	

7.4.2.5. Headways used for GTFS

We were able to collect data on 154 of the 157 trips in our initial plan. Three trips were excluded from our plan because the field researchers raised concerns about the safety of the terminals they originated at.

Each trip was observed for five instances[14]: three instances during weekdays and two instances on saturdays. Each instance corresponds to a 45 minute time slot that a field researcher spent observing a particular trip, with a specified beginning and end time. We calculate the frequency of operation for each instance.

For the accessibility analysis, which is modelled during the morning rush hour, we need all trips to have morning rush hour frequencies. Morning rush hours are assumed to be between 6am - 10am.

- In the case where we have an instance collected during the morning rush hour, it is used directly in the GTFS.

Not all trips were observed during the morning rush hour period, and so to estimate morning rush hour frequencies of the remaining trips we did the following:

- If the trip was only observed during the weekday evening rush hour period (2pm - 6pm), we used that frequency.
- If the trip was not observed in either the morning or evening rush hour period, we calculate the average frequency of the different instances when it was observed and use that value
- For any trip in our database that was not observed during this data collection assignment[15], we assign to it a frequency value based on other trips of the same agency. We calculate an average morning rush hour frequency for each agency (CTA, CTA_M, COOP, P_O_14, P_B_8) and assign these averages to the remaining trips based on their agency.

7.4.3. Operational Data for Future Projects

Since future projects are yet to be implemented, there is no operational data available for them. The only information that currently exists is their routes and stop locations. This necessitates making assumptions on headway at peak hour (as our accessibility analysis is done for the weekday morning rush hour). We base the operational schedules of the future metro lines on the existing ones, using headway figures of the first phase of the third metro line as a reference for the headway of the future lines. For the electric train, we base the speed and headway on existing infrastructure in other parts of the world.

[14] Small variations exist, where some trips were not observed for the full five instances.

[15] Our database has 366 unique trips, but due to time and budget constraints, we were only able to collect frequency data on 154 of those trips

7.5. Appendix E: GTFS used for Accessibility Analysis

Many different service providers are currently offering collective transport in the GCR. The decision of which ones to include in our accessibility analysis is dependant on how these services weigh up against an ideal public transport service. This comparison is done by checking how each service complies with the seven categories that are used to evaluate public transport (as detailed in the table below). We chose to exclude newly emerging collective transport services as they do not meet the requirements for frequency of operation or cost, and are dependant on the user having a smartphone to access the service.

Table E19: Evaluation of different collective transport services

Operator	Coverage	Availability	Frequency	Cost		Regulation	Reservation
Included within Accessibility Analysis							
CTA Bus	GCR	All day	Low-High	Low	0.16 EGP/km	Yes	Not necessary
Private Sector Minibus (Concessions from CTA)	GCR	All day	Medium-High	Low	0.16 EGP/km	Yes	Not necessary
Regulated informal transit (Microbus)	GCR	All day	Medium-High	Medium	0.34 EGP/km	Yes	Not necessary
Regulated informal transit (Suzuki)	GCR	All day	Medium-High	High	0.62 EGP/km	No	Not necessary
Unregulated informal transit (BOX)	GCR	All day	Medium-High	-	-	Yes	Not necessary
Cooperative Minibus	GCR	All day	Medium-High	Medium	0.29 EGP/km	Yes	Not necessary
Cairo Metro	Central & Inner Cairo	All day	High	Medium	0.31 EGP/km	Yes	Not necessary
Excluded from Accessibility Analysis							
SWVL	GCR	Peak hours only		High		No	Necessary
Buseet	GCR	Peak hours only		High		No	Necessary

For those services that will be part of our analysis, data is required:

Bus services (formal and informal) have been previously captured in data created by the consultant as part of a project called Digital Cairo. In partnership with Takween for Integrated Community Development (TICD) and Digital Matatus, the consultant collected basic route and system adequacy data using mobile devices for 216 unique bus routes during the winter of 2017-18. This data is available in the GIS and GTFS formats. The geographic scope of the data is the GCR, focusing on the NUCs. We collected all intra-city services originating and ending within six NUCs: El-Sheikh Zayed City, 6th of October City, New Cairo, El-Obour City, El-Shorouk City and 10th of Ramadan City. These services include routes within NUCs, connecting NUCs with each other and connecting NUCs with inner city Cairo. This dataset is referred to as Digital Cairo GTFS 2018 (Phase 1)

In 2019, we captured formal and informal bus services operating in Inner and Central Cairo. In a 3 month data collection effort funded by the World Bank, we mapped 600 unique routes; 180 CTA routes, 63 minibus routes, and 357 informal transit routes. This dataset was merged with that from Digital Cairo GTFS 2018 (Phase 1), and combined GIS layers and GTFS feeds were created.

The combined dataset, referred to as TfC GCR GTFS 2019, is used in our analysis. Details on the operational data for these trips exists in Appendix D. Operational data of the Cairo Metro for 2018/2019, as produced by the National Authority for Tunnels, has also been acquired by the consultant. This data was used to create a GTFS dataset for the Cairo metro, which was added to the TfC GCR GTFS 2019. A breakdown of the GTFS data available for the existing public transport network is in the table below

Table E20: Data available for study

Service	Scope	No. of Trips	No. of Routes	Network Length (km)	Operational Data
Box informal transit	majority of inter and intra city services in the GCR	21	11	115 km	Partially Available
informal transit 14 seater microbuses	majority of inter and intra city services in the GCR	687	398	11671 km	Partially Available
CTA buses	majority of inter and intra city services in the GCR	388	204	9888 km	Partially Available
Minibuses licensed by CTA	majority of inter and intra city services in the GCR	147	75	4079 km	Partially Available
Cooperative informal transit 29 seater	majority of inter and intra city services in the GCR	56	37	879 km	Partially Available
informal transit 8 seater Suzuki Chevrolet or DMF	subset of inter and intra city services in the GCR	132	75	891 km	Partially Available
Mwasalat Misr Buses	Entire Network	24	12	847 km	Available
Cairo Metro	Entire Network	6	3	147 km	Available

Field research was carried out as part of this study to obtain operational data for some of the trips in our database. The details of the field research is outlined in Appendix D.

The GTFS used for the 2022 accessibility analysis includes a completed Cairo Metro Line 3, Phase 1 of Cairo Metro Line 4, as well as the Electric Train connecting El Salam City to the New Administrative capital. The stops for each of these services are documented in presentations made by representatives of both the Ministry of Transport and the National Authority for Tunnels (Mahdi 2018; National Authority for Tunnels, n.d.). However, the operational data of these future services does not exist. We base the operational schedules of the future metro lines on the existing ones, using headway figures of the first phase of the third metro line as a reference for the headway of the future lines. For the electric train, no operational data exists, so we base the speed and headway on existing infrastructure in other parts of the world.

7.5.1. Adding Future Projects in Accessibility Analysis

7.5.1.1. List of all Future Public Transport Projects

Implementation of Line 3 of the Cairo Metro is well underway, with the first two phases already completed. The remaining two phases of line 3 are under construction, with the line expected to be completed by 2023. It is expected to improve accessibility across the Eastern-Western axis of the capital, and is funded by a €2 billion loan from AFD and EIB. Work has also begun on the first phase of Line 4 of the metro, which is meant to connect 6th of October City and New Cairo to the metro network. Construction will be funded through a €1.75 billion soft loan from JICA. Construction will also begin soon on Line 5 and 6. Line 5 is expected to go from Rod El Farag to Nasr City, cutting across all other metro lines and improving accessibility. It will cost around $4 billion, but funding has yet to be secured. Line 6 is designed to reduce pressure on Line 1 which is currently operating above its design capacity (MoT, 2018). It will be financed by a $4.5 billion soft loan from the Canadian Government and constructed by the Canadian company Bombardier, who have already conducted a feasibility study for the project (Ahram Online, 2017).

Line 1 will see an increase in capacity by 40% due a reduction in headway through a €205 million loan by the European Bank for Reconstruction and Development (EBRD) (Egypt Today, 2018). An extension of Line 2 from Shubra El Kheima to Qalyub has been recently tendered for a feasibility study .

Two monorails on either side of the capital have also been studied. The first will connect the cities of 6th of October and Sheikh Zayed to Giza. At 35 km in length, it is planned to start at the Industrial Zone in 6th of October and terminate at the Cairo University station at the end of the third metro line. The second monorail will be 52 km in length, connecting Nasr City to the New Administrative Capital (MoT, 2018). The Ministries of Housing and Transportation have formed a joint committee and invited consultants to submit their bids for the projects (Akhbar El Youm, 2018). It remains unclear how these two lines will be funded.

A Light Rail Train (LRT) will also be built by CRRC Corporation Limited to connect Cairo to the New Administrative Capital. The train, commonly known as the 'Electric Train', will run from the newly proposed Adly Mansour Station at the Eastern periphery of Cairo, passing through Obour, Shorouk and Badr on its way to the New Administrative Capital. Funding is provided by the Aviation Industry Corporation of China (AVIC) through a $1.2 billion loan facilitated by the Chinese government. (Reuters 2017) It is expected to be operated by the China Railway Engineering Corporation (CRECG) and enter into service end of 2020, with a headway of 15 minutes between trains.

A High-Speed Rail (HSR) connecting Ain El Sokhna with El Alamein City is being contemplated. The first phase of the project will be 122 km of rail from 6th of October City to the New Administrative Capital. This will be followed by a 320km extension from 6th of October to Alamein City. The final phase will be 92 km, connecting the New Administrative Capital to Ain El Sokhna.

Seven bus routes are in the process of being implemented from Inner City Cairo to the western section of the GCR as part of the BRT Light services to be provided by Mwasalat Misr. These routes will be implemented by Mwasalat Misr who have also begun building bus terminals and park-and-ride facilities in the cities of Sheikh Zayed and 6th of October. This BRT Light service is proposed and funded by the Sustainable Transport Project (STP).

A pre-feasibility study for two BRT corridors was completed by ITDP. The corridors aim to connect Inner City Cairo with the suburbs on either side (ITDP, 2015). A different pre-feasibility study for internal BRT systems in New Cairo and 6th of October was commissioned by EBRD in 2013 (EBRD, 2015). This project has not progressed past the pre-feasibility phase and it remains unclear whether there are plans to proceed with implementation of BRT systems on the studied corridors.

The Governor of Cairo signed a protocol with UN-Habitat for the implementation of a bike-sharing system in Downtown Cairo. The first phase, which is supposed to include 300 bicycles as well as dedicated bike lanes, is funded by a $1.5 million grant from by the Drosos Foundation (Egypt Independent, 2017).

Table E21: Future transport infrastructure projects in the GCR

Project	Funding	Cost	Timeline	Corridor	Status
Rail					
Metro					

Line 1 - Renovation	EBRD, AFD and EIB	€749 million	2023	-	Under Implementation
Line 2 - Extension	-	-	-	Shubra EL Kheima - Qalyub	Pre-Feasibility
Line 3 - Phase 3	**AFD and EIB**	**EGP10.4 billion + €1.5 billion**	**2022**	**Attaba – KitKat : KitKat - Rod El Farag : KitKat - Cairo University**	**Under Implementation**
Line 3 - Phase 4a	**AFD and EIB**		**Dec 2018**	**Heliopolis - Nozha**	**Under Implementation**
Line 3 - Phase 4b	**AFD and EIB**	**EGP5.37 billion + €485 million**	**Dec 2019**	**Nozha - Hikestep**	**Under Implementation**
Line 3 - Phase 4c	**-**		**-**	**Heliopolis - Cairo Airport**	**Under Study**
Line 4 - Phase 1	JICA	EGP30 billion + €1.75 billion	-	6th of October City - Fustat	Under Implementation
Line 4 - Phase 2			-	Fustat - Al Rehab City	Under Study
Line 5	-	$4 billion	-	Nasr City - El Sahel	Under Study
Line 6	Canadian Government	$4.5 billion	-	Elkhosous - New Maadi	Under Study
Light Rail Train					
Electric Train	**Chinese Government**	**$1.2 billion**	**2020**	**El Salam City - New Administrative Capital**	**Under Implementation**
Monorail					
6th of October	-	-	-	6th of October City - Gameat El Dewal	Under Study (Khatib & Alami)
New Administrative Capital	-	-	-	Nasr CIty - New Administrative Capital	Under Study (Bombardier)
High Speed Rail					
Inter-City	-	-	-	Ain Al Sokhna - El Alamein	Under Study
Bus					
Bus Service					
BRT Light services	**Mwasalat Misr, UNDP, NUCA**	**-**	**2019**	**7 Bus Lines from Inner City Cairo to The Western Section of the GCR**	**Under Implementation**
Mwasalat Misr	Mwasalat Misr	~$165 million		6 Bus Lines (2018) Planned Expansion 60 Lines (2020)	Under Implementation
Bus Rapid Transit					
6th of October to Inner City Cairo	ITDP, Un-Habitat, NUCA	-	-	Remaya Square - Ahmed Orabi St	Pre-Feasibility
New Cairo to Inner CIty Cairo	ITDP, Un-Habitat, NUCA	-	-	AUC (New Cairo) - Attaba	Pre-Feasibility

6th of October	EBRD			26th of July Corridor/ Giza - Al Wahat Road / Waslet Dahshur	Pre-Feasibility
New Cairo to Inner CIty Cairo	EBRD			Southern 90 Axis/Al Sadat Axis	Pre-Feasibility
Bicycles					
Bike Sharing System					
Downtown Bike Sharing System	Drosos Foundation	$1.5 million		Downtown Cairo	Under Study

7.5.1.2. Future Projects to be Completed by 2022

We assume that the proposed PPTI will be implemented by 2022, and so we choose to include in our analysis all projects expected to be completed by then. Such an analysis would have an added benefit of highlighting potential complementaries between specific PPTI and planned infrastructures; as well as potential duplicates.

These future infrastructure projects are added through the creation of a TfC GCR GTFS 2022 dataset: A combination of the TfC GCR GTFS 2019 dataset, and a simulation of all new infrastructure scheduled to be finished in the year 2022; namely: The completion of the Cairo Metro Line 3 (Phases 3, 4a, 4b) and the first phase of Line 4, the Electric Train (El Salam City - New Administrative Capital), and the BRT Light service provided by Mwasalat Misr to link the cities of Sheikh Zayed and 6th of October with Inner Cairo.

Table E22: Future transport infrastructure projects expected to be completed by 2022

Project	Timeline	Corridor	Status
Rail			
Metro			
Line 3 - Phase 3	2022	Attaba – KitKat : KitKat - Rod El Farag : KitKat - Cairo University	Under Implementation
Line 3 - Phase 4a	Dec 2018	Heliopolis - Nozha	Under Implementation
Line 3 - Phase 4b	Dec 2019	Nozha - Hikestep	Under Implementation
Line 3 - Phase 4c	-	Heliopolis - Cairo Airport	Under Study
Line 4 - Phase 1	2022	6th of October City - Fustat	Under Implementation
Light Rail Train			
Electric Train	2020	El Salam City - New Administrative Capital	Under Implementation
Bus			
Bus Service			
BRT Light services	2019	7 Bus Lines from Inner City Cairo to The Western Section of the GCR	Under Implementation

7.6. Appendix F: Accessibility Analysis Calculation

The chosen metric for accessibility is a constraint-based approach computed using the number of opportunities available to a place within a threshold travel cost of time. The travel time using public transport is calculated using TfC GCR GTFS 2019 data for every origin-destination pair in the GCR and the sum of opportunities for each origin is calculated and weighted by the population. For every hexagon of analysis *i*, the number of modelled job opportunities at destination hexagons *j* that can be reached within a threshold transport time of 1 hour by public transit is summed. This is shown in the following equation

$$Accessibilty_i = \sum_j Opportunities_j W_j$$

Where W is a binary variable of 1 if *j* is within 1 hour from *i* by public transport and 0 otherwise.

This will create an "Accessibility Score (PT, Present)" dataset for travel using public transport, which is disaggregated (1) by area unit of analysis, H3 hexagons in our case and (2) weighted average accessibility scores by NUC.

The final step is to create an Accessibility Indicator for the entire study area. This works through weighting the population of the area units. This means that each area unit's accessibility measure will be multiplied by its population and the sum of all the weighted accessibility will be divided by the sum of the population in the hexagons in the urban area. This reveals the (3) metropolis-wide Accessibility Indicator. Dividing this Accessibility Indicator by total employment across the metropolis yields the percentage of the employment opportunities accessible.

$$\textbf{Accessibility Indicator} = \frac{\sum_i Accessibility_i * Population_i}{\sum_i Population_i}$$

7.6.1. Methodology for the Accessibility Analysis

Utilising the various data sets we procured and produced, we computed the percent of all opportunities reachable to every area of analysis, in our case, the H3 hexagon unit. This will leverage the Open Trip Planner software which will compute an accurate geographic area, a polygon, representing the space that is reachable within one hour of travel by public transport under different scenarios of public transport. This will be enabled using the GTFS we have produced which communicates the routes and stops of the formal and informal public transport network of Cairo.

With the reach polygon for each hexagon, the number of opportunities that fall within was summed and saved as an attribute of that hexagon. Examples of the difference in reach between an NUC, New Cairo, and Inner Cairo can be seen in the figure below. The number of employees assigned to each point in the Opportunities dataset was computed according to our methodology for the Spatial Employment Model. The details can be found in Appendix B. Finally, the number of opportunities will be used to calculate the percent of opportunities reachable to each hexagon and that ratio will be used to rank the hexagons based on their accessibility to opportunities. The hexagon's individual accessibility measures were combined, weighted by the hexagons population, to compute a summary accessibility analysis for each NUC as well as the entire metropolitan area.

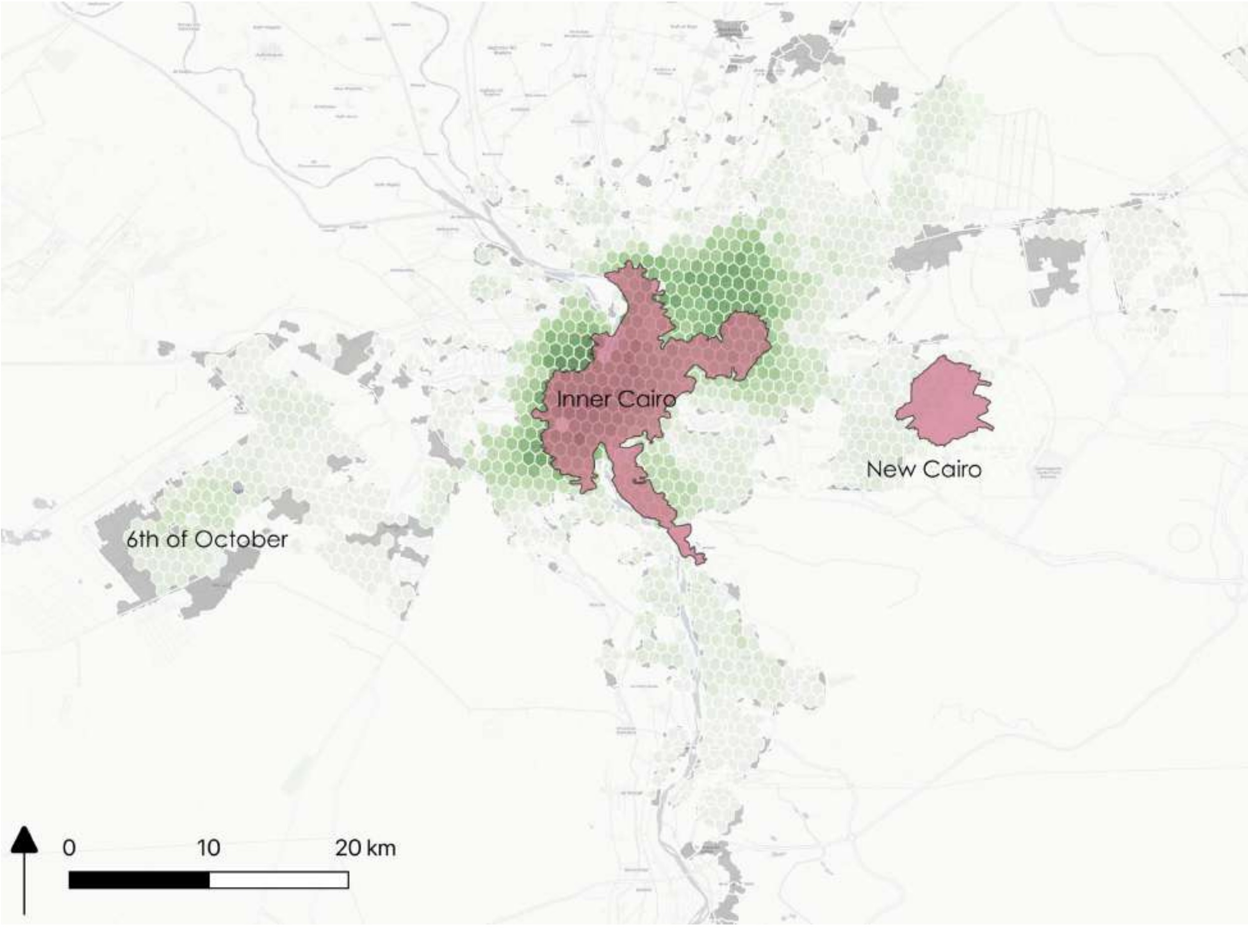

Figure 38. The reach polygons computed by Open Trip Planner showing the difference in reach between New Cairo and Inner Cairo. The underlying hexagons give an idea of the accessibility results for the 2019 present scenario, the darker green indicates a higher accessibility score.

7.6.2. Limitations of the Accessibility Analysis

The accessibility measure described above has some limitations. First, it only considers two of the components of accessibility, namely transport and land use. It does not take into account the times at which the public transport is functioning nor the times at which the destination opportunities are available. Since our analysis prioritizes the weekday work commuter, we assume the availability throughout the system at normal Cairo working hours for both the transport system as well as the opportunities.

Another aspect of the temporal component that is limited in our analysis is the cutoff of 60 minutes threshold which may be unrealistic for some commuters who are willing to travel more or less.

The individual component of accessibility, one which describes the commuter's ability to part-take in the opportunities, is missing. Theoretically, this component would account for the willingness or ability of an individual to partake in a specific opportunity; medicine related employment opportunities are only relevant to people working in the field of medicine, not the entire population. To take this into account in the analysis, we would require data on socio economic, educational, social, religious, and other personal preferences of all residents. This would limit the actual number of opportunities perceived to be available to an individual so that it matches more closely with reality. This would require a level of data granularity not yet reached in many places in the world. We overcome this by assuming that citizens are spread out randomly and that each area will have an equal probability of containing citizens that may respond to all the available employment opportunities. In other words, the doctors/engineers/actors are not all segregated in one area but live throughout the city in equal probability. This assumption is fair and adequate.

The analysis is limited to areas that lie within a 500m catchment area of the full TfC GCR GTFS 2019 network.

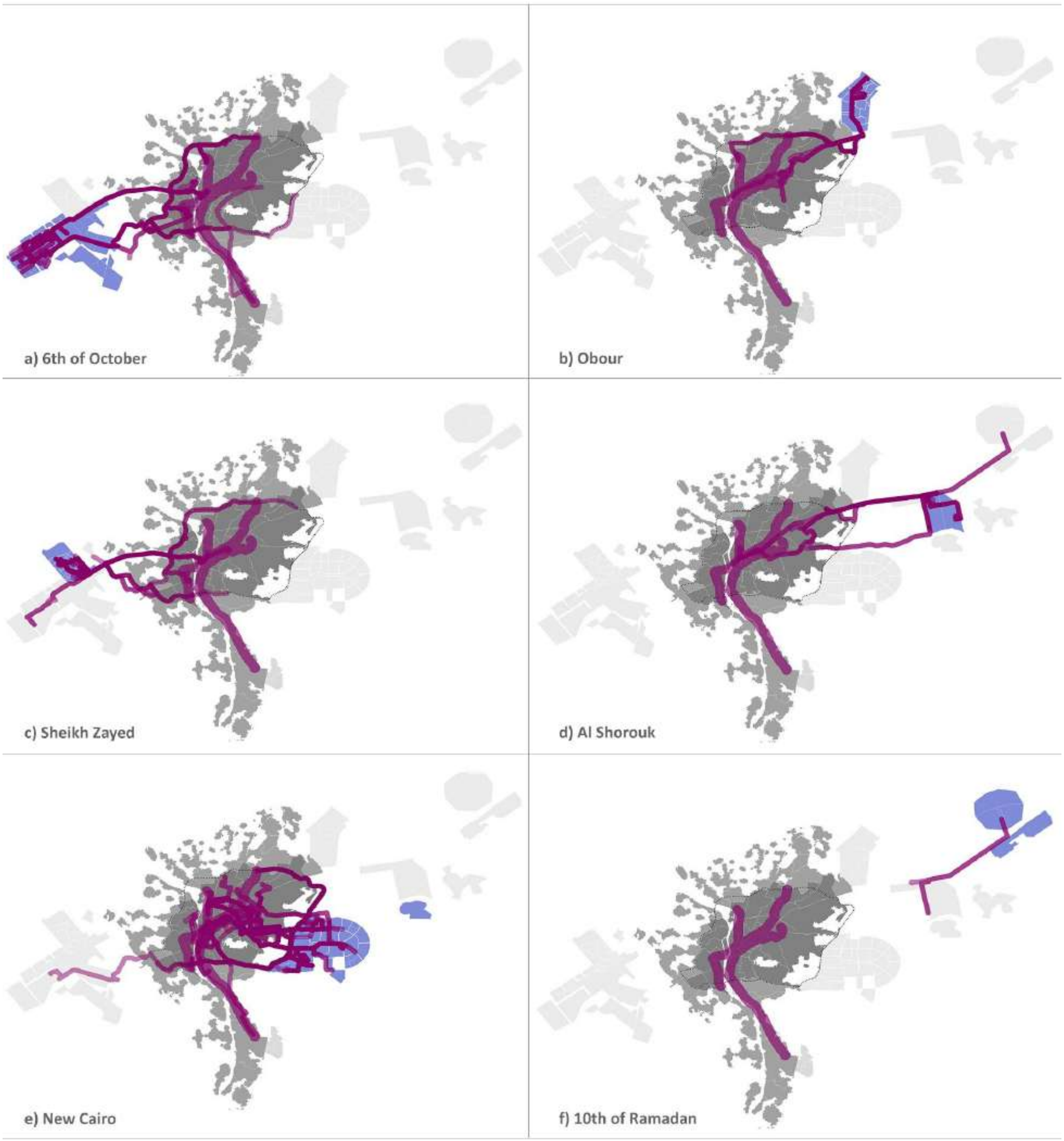

Figure 37: Digital Cairo Bus GTFS 2018 (Phase 1) - Coverage per NUC

7.7. Appendix G: Methodology for choosing Park and Ride Facilities

The Park and Ride Facility locations are limited to locations along the identified PPTI routes, The reason for this is that high patronage of the facilities is only guaranteed if there is a service that is both high in quality and frequency that can attract car owners.

Locations are determined by first analyzing congestion patterns on the three identified PPTI routes. Travel time throughout the day on the 19 main corridors of the GCR has been captured in the TfC Travel Time Matrix (PT, Present) dataset (detailed in Appendix C). This allows us to determine the beginning and end of congestion zones or choke points; these are prime locations for PnR facilities.

Candidate locations that are closest to congestion zones are shortlisted as potential PnR facilities. The next step is to understand commuting patterns of car users. Ride-hailing data is used as a proxy for all private vehicle commuting patterns, the assumption being that those that use ride-hailing services are the same socio-economic demographic that are likely to own a car. The data shows the top pick-up and drop off points of ride-hailing users, allowing us to infer the demand patterns along the PPTI routes.

Potential PnR facility locations are selected at locations that allow them to accommodate that demand, with an emphasis on proximity to residential areas in the NUCs. These areas are inferred from both the morning pick-up points and the evening drop off points from the ride-hailing data.

The recommendations take into account land-use restrictions. This is only done on a macro level, based on the knowledge that land in Inner and Central Cairo is dense and has a high value, making it expensive to build in. The NUCs, however, are characterized by low density and large patches of desert, making them more practical for new infrastructural development.

7.8. Appendix H: Last Mile Solutions

7.8.1. Pedestrian Connectivity

Pedestrian connectivity is calculated around all transit hubs surrounding the 3 final PPTIs. The calculation is done by computing the reach of each hub for pedestrians. This allows us to compare walkability between different regions and determine relationships of the different street networks to their respective catchment areas.

We determine the possible distance walked from a transit hub within a threshold time of 10 minutes. An isochrone of the potential area reached is compared with the circle obtained if we assume a radial path extending outwards from the center for a distance equivalent to walking at 1.4 m/s for 10 minutes. The area of the isochrone is divided by that of the circle to determine a potential walking ratio for the transit hub.

We calculate this ratio for a select number of areas that are known for being pedestrian friendly, and use their scores as a benchmark for comparison. Areas with relatively low ratios are visually inspected and recurring problems that impede walking are identified.

We also calculate the population and employment opportunities in the catchment area of each transit hub; areas with high walking ratios do not necessarily have high foot traffic. We aim to show that foot traffic is closely linked to land use.

7.9. Appendix I: Public Transport in the GCR Statistics

Table I-1: Different vehicle types

Code	Name	Description	Seats
BOX	-	Informal - Modified Pick-up Truck	~9
CTA	CTA	Formal - Cairo Transport Authority Bus	49
CTA_M	CTA Minibus	Formal - Private Company Minibus Licensed by the CTA	29
COOP	Cooperative	Informal - Cooperative transport Minibus	29
CTA_F	CTA Ferry	Formal - Ferry Services operated by the CTA	NA
MM	Mwasalat Misr	Formal - High Quality Bus Service	44
P_B_8	Suzuki	Informal - Van	7
P_O_14	Microbus 14 Seater	Informal - Microbus	14

Tables I-2 to I-7 contain statistics on output of the mapping operation, the average distance travelled, the total route length, number of unique routes (including directionality) mapped, average trip duration recorded during mapping[16], the average fare in EGP[17] and the average fare cost per km of trips. Columns refer to different vehicle types as previously identified in table I-1. Rows refer to City Pairs. Each City Pair consists of the aggregated geographic area of origin and destination, as visualised in Figure 17.

CTA services and P_O_14 (Informal 14-Seater Microbus) services operating within the Central and Inner Zones of the Greater Cairo Region merit special focus, as together they represent three quarters of the surveyed routes. (See table I-2 in the appendix) They are highlighted in light blue. There are almost twice as many informal routes as formal routes. Informal routes tend to be a third shorter, take a third of travel time (i.e. avoid highlight congested routes and operate faster), command the same fares but at double the cost per km (i.e. tickets cost about the same price, but when averaged over distance reveal double the cost per unit of travel).

[16] The Winter 2017-2018 and Summer 2019 mapping exercise should not be seen as representative samples for trip durations, as times of high congestion were avoided during the field research.

[17] Fare data was standardized for Q3 2019: Trips mapped after the July 2019 Price Hike were included as is. CTA routes were modelled based on the published fixed fares sold by the CTA. Informal Transport Routes were either sourced from secondary sources, or modelled using a multiple linear regression model. Details of the updating of the fares are provided in the "Update to GCR Accessibility Analysis (Mapping Central and Inner-Cairo)" report.

Table I-2: Number of unique trips found and represented in the dataset, aggregated by City Pairs.[18]

City Pair	BOX	COOP	CTA	CTA_F	CTA_M	MM	P_B_8	P_O_14
Between western NUCs							19	2
Cross GCR NUC travel								1
Cairo & Qalyubia - Eastern NUCs		4	21		16	1	1	29
Eastern NUCs - Cairo & Qalyubia		6	22		14	1	2	29
Cairo & Qalyubia - Western NUCs			5					8
Western NUCs - Cairo & Qalyubia		1	4					12
Eastern NUCs - Giza			1		1		2	6
Giza - Eastern NUCs			1		1		2	6
Giza - Western NUCs		1	1					12
Western NUCs - Giza		1	1					12
Within GCR Central/Inner		43	310	2	121		31	510
Within NUC	17						57	7
Other	4	1	33	2	2		22	67

Table I-3: Average trip duration in minutes of trips represented in the dataset, aggregated by City Pairs.

City Pair	BOX	COOP	CTA	CTA_F	CTA_M	MM	P_B_8	P_O_14
Between western NUCs							11.9 min	6.0 min
Cross GCR NUC travel								58.0 min
Cairo & Qalyubia - Eastern NUCs		41.2 min	101.2 min		105.6 min	64.1 min	27.9 min	28.3 min
Eastern NUCs - Cairo & Qalyubia		34.7 min	91.9 min		113.7 min	78.3 min	28.6 min	28.6 min
Cairo & Qalyubia - Western NUCs			90.1 min					54.7 min
Western NUCs - Cairo & Qalyubia		86.5 min	87.0 min					65.1 min
Eastern NUCs - Giza			90.3 min		139.5 min		41.5 min	36.2 min
Giza - Eastern NUCs			51.0 min		97.8 min		24.9 min	44.8 min
Giza - Western NUCs		24.6 min	80.2 min					37.6 min
Western NUCs - Giza		32.7 min	88.4 min					38.9 min
Within GCR Central/Inner		31.6 min	72.0 min	22.5 min	81.1 min		14.9 min	26.7 min
Within NUC	15.9 min						13.7 min	14.6 min
Other	15.0 min	38.3 min	81.5 min	5.3 min	112.4 min		14.0 min	30.9 min

[18] Codes of the different modes of transport are explained in table D16 in the appendix.

Table I-4: Average distance of services represented in the dataset, aggregated by City Pairs.

City Pair	BOX	COOP	CTA	CTA_F	CTA_M	MM	P_B_8	P_O_14
Between western NUCs							6.6 km	2.8 km
Cross GCR NUC travel								71.3 km
Cairo & Qalyubia - Eastern NUCs		36.4 km	48.8 km		38.9 km	40.3 km	24.4 km	24.7 km
Eastern NUCs - Cairo & Qalyubia		32.7 km	47.8 km		39.5 km	40.1 km	19.5 km	23.6 km
Cairo & Qalyubia - Western NUCs			48.4 km					50.0 km
Western NUCs - Cairo & Qalyubia		55.9 km	50.5 km					51.7 km
Eastern NUCs - Giza			46.9 km		45.6 km		26.8 km	37.8 km
Giza - Eastern NUCs			41.0 km		35.6 km		27.1 km	41.4 km
Giza - Western NUCs		24.6 km	46.9 km					34.6 km
Western NUCs - Giza		27.8 km	51.2 km					34.7 km
Within GCR Central/Inner		11.3 km	21.8 km	3.6 km	26.1 km		5.6 km	14.0 km
Within NUC	6.5 km						7.0 km	9.2 km
Other	5.8 km	16.0 km	36.5 km	0.6 km	58.4 km		7.0 km	22.6 km

Table I-5: Cumulative distance of services represented in the dataset, aggregated by City Pairs.

City Pair	BOX	COOP	CTA	CTA_M	MM	P_B_8	P_O_14
Between western NUCs						100 km	6 km
Cross GCR NUC travel							61 km
Cairo & Qalyubia - Eastern NUCs		126 km	873 km	509 km	173 km	21 km	590 km
Eastern NUCs - Cairo & Qalyubia		170 km	878 km	469 km	178 km	33 km	573 km
Cairo & Qalyubia - Western NUCs			203 km				341 km
Western NUCs - Cairo & Qalyubia		49 km	171 km				532 km
Eastern NUCs - Giza			36 km	38 km		49 km	209 km
Giza - Eastern NUCs			34 km			46 km	240 km
Giza - Western NUCs		21 km	42 km		105 km		323 km
Western NUCs - Giza		26 km	45 km		106 km		367 km
Within GCR Central/Inner		487 km	6,630 km	2,963 km	211 km	171 km	7,046 km
Within NUC	97 km					334 km	72 km
Other	18 km		975 km	100 km	74 km	136 km	1,312 km

Table I-6: Average fare in EGP represented in the dataset, aggregated by City Pairs.

City Pair	COOP	CTA	CTA_M	MM	P_B_8	P_O_14
Between western NUCs					EGP 3.2	EGP 4.0
Cross GCR NUC travel						EGP 12.5
Cairo & Qalyubia - Eastern NUCs	EGP 6.0	EGP 5.8	EGP 5.0	EGP 15.0	EGP 6.5	EGP 5.9
Eastern NUCs - Cairo & Qalyubia	EGP 5.8	EGP 5.8	EGP 5.0	EGP 15.0	EGP 5.8	EGP 5.8
Cairo & Qalyubia - Western NUCs		EGP 5.6				EGP 8.5
Western NUCs - Cairo & Qalyubia	EGP 9.0	EGP 5.8				EGP 8.8
Eastern NUCs - Giza		EGP 5.0	EGP 5.0		EGP 6.5	EGP 8.3
Giza - Eastern NUCs		EGP 5.0			EGP 6.5	EGP 9.3
Giza - Western NUCs	EGP 6.0	EGP 6.0				EGP 6.8
Western NUCs - Giza	EGP 5.0	EGP 6.0				EGP 6.7
Within GCR Central/Inner	EGP 3.2	EGP 4.1	EGP 5.1		EGP 3.5	EGP 4.1
Within NUC					EGP 3.5	EGP 3.3
Other	EGP 3.5	EGP 4.9	EGP 7.0		EGP 3.9	EGP 5.0

Table I-7: Average fare cost per km of trips represented in the dataset, aggregated by City Pairs.

City Pair	COOP	CTA	CTA_M	MM	P_B_8	P_O_14
Between western NUCs					0.62 EGP/km	1.82 EGP/km
Cross GCR NUC travel						0.18 EGP/km
Cairo & Qalyubia - Eastern NUCs	0.16 EGP/km	0.12 EGP/km	0.13 EGP/km	0.37 EGP/km	0.27 EGP/km	0.30 EGP/km
Eastern NUCs - Cairo & Qalyubia	0.18 EGP/km	0.13 EGP/km	0.13 EGP/km	0.37 EGP/km	0.30 EGP/km	0.27 EGP/km
Cairo & Qalyubia - Western NUCs		0.12 EGP/km				0.17 EGP/km
Western NUCs - Cairo & Qalyubia	0.16 EGP/km	0.12 EGP/km				0.17 EGP/km
Eastern NUCs - Giza		0.11 EGP/km	0.11 EGP/km		0.24 EGP/km	0.21 EGP/km
Giza - Eastern NUCs		0.12 EGP/km			0.24 EGP/km	0.22 EGP/km
Giza - Western NUCs	0.24 EGP/km	0.13 EGP/km				0.21 EGP/km
Western NUCs - Giza	0.18 EGP/km	0.12 EGP/km				0.21 EGP/km
Within GCR Central/Inner	0.33 EGP/km	0.21 EGP/km	0.21 EGP/km		0.77 EGP/km	0.42 EGP/km
Within NUC					0.71 EGP/km	0.70 EGP/km
Other	0.22 EGP/km	0.14 EGP/km	0.12 EGP/km		0.66 EGP/km	0.29 EGP/km