Light Rail Tram for Khartoum, Sudan

Prefeasibility Report

Building on the Transport for Khartoum Transportation Plan to propose a Primary Tram Network Phased over 10-15 years

Prepared by KISCO

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Introduction and Summary

Khartoum is the political and commercial centre of Sudan, with a rapidly growing urban population. The city has a population of 7.69 million and is expected to reach 15 million by 2030.

Public and non-motorised transport (primarily walking) are the most widely used modes of transport in Khartoum, with a share of 25% and 50% respectively. Public transport is predominantly provided by a large number of small, privately owned buses. These services are overcrowded, operated in congested mixed traffic, and make use of old, unreliable and inefficient vehicles. Many people walk due to a lack of service availability, or an inability to afford alternative means of commuting.

Expanding the transit system is essential to connect people to schools, jobs and their communities. With this growth, transit and road traffic congestion levels are expected to worsen and commute times to become longer, which will lead to negative impacts to Khartoum's citizens quality of life and environment.

This problem is underpinned by three critical issues that impact travellers and impede regional growth:

- Issue 1 – Crowding and capacity – the existing transportation network will not be able to provide reliable, fast, and frequent mobility that meets future population growth.
- Issue 2 – Coverage and network resilience – the existing transportation network is based on aging infrastructure, old and inefficient vehicles and limited enforcement and management capacity **-** any minor disruption can mean significant delays throughout KRT
- Issue 3 – Community growth and transport scarcity – the existing transportation network does not provide transit connections to much of downtown Khartoum. In many regions finding public transport is a rarity and becomes scarcer with unplanned expansion.

Image 1 - Drone Footage showing queues at Petrol Station amid fuel shortages – Khartoum, Sudan

1.0 Khartoum Background

Khartoum is the Capital of Sudan, situated at the converge of two of the world's most longest and strongest rivers, the White Nile flowing from Lake Victoria in Uganda and the Blue Nile originating from Lake Tana in Ethiopia. The convergence of the rivers at Khartoum creates a low lying, fertile, flat land surrounded by the meandering river, agriculture and abundance of fresh water.

Khartoum has urbanised over the course of the last century and considerable investment has been made into the city's infrastructure needs to meet the needs of the growing population.

Khartoum's population growth can be attributed to movements and migration from rural to urbanised regions, with Khartoum becoming the favourite destination for new residents, business and asylum from all over the East Horn of Africa.

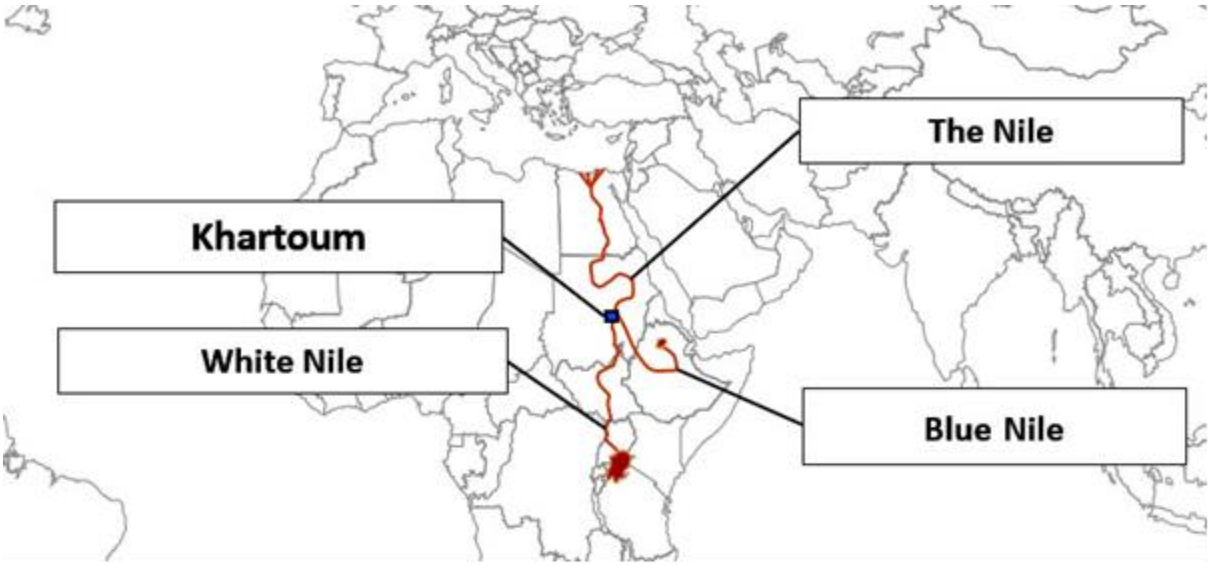


Figure 1 - Location of the Blue and White Niles meeting

1.1 Khartoum's Population Surge

Sudan's total population is 42 million and Khartoum the Capitals current population figures is 7,687,547 and has been increasing around 8% annually which is reflected in the number of schools, hospitals, multi-storey residential buildings and increased number of road-users and vehicle ownership.

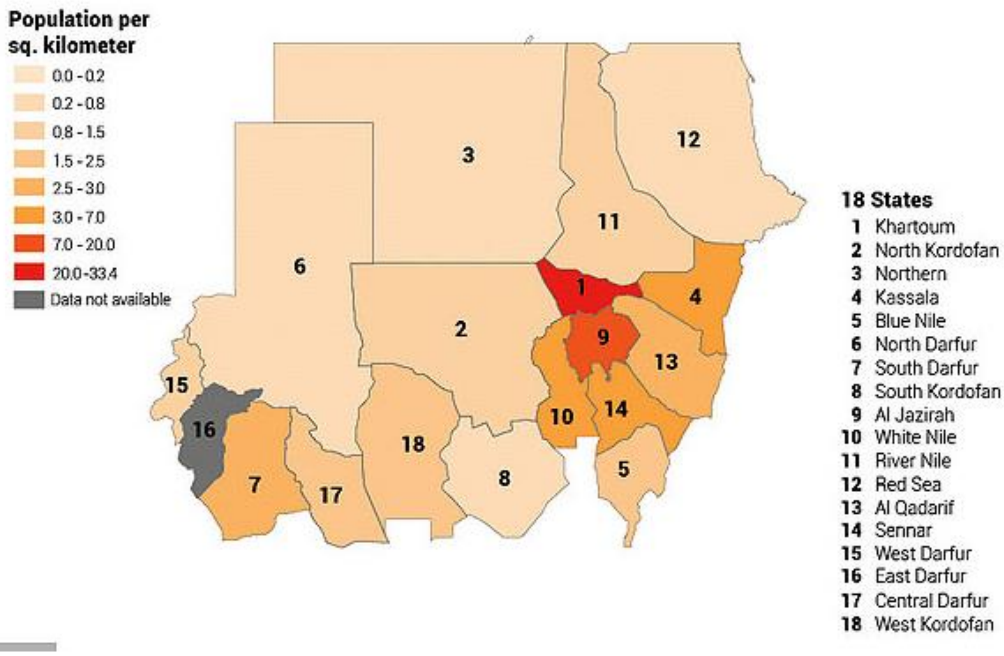


Figure 2 – Population per km² per state

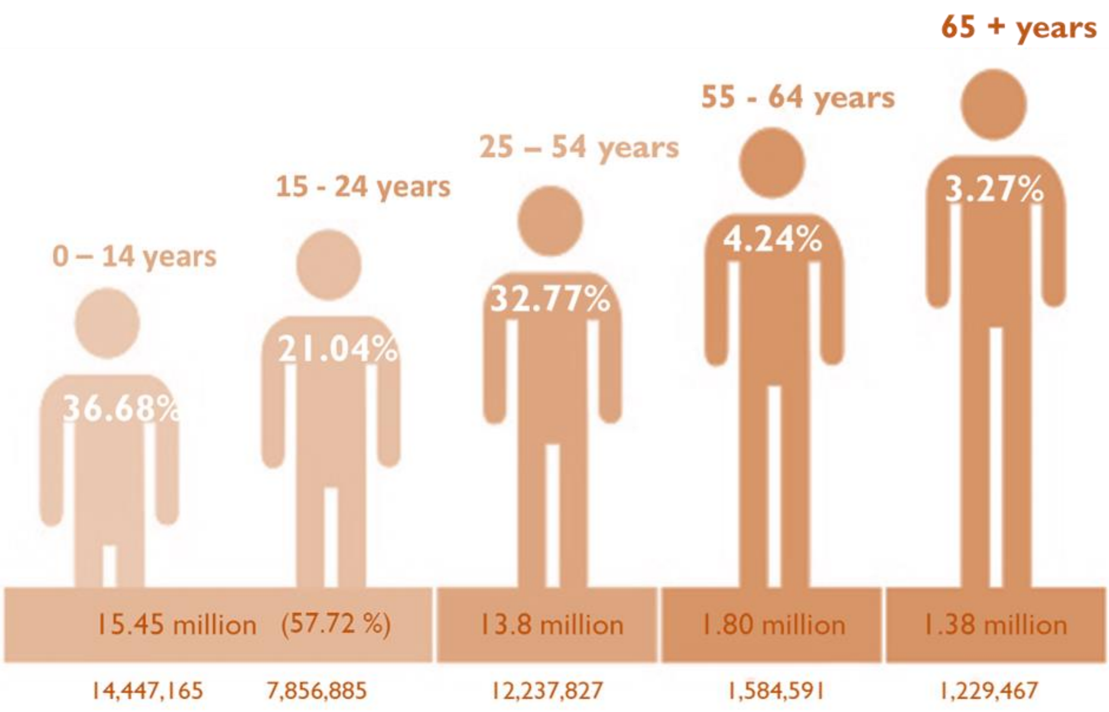


Figure 3 – Age range to population percentages

Over the past 75 years Khartoum has developed into one of the densist cities in the world in which the central business district regions around the river bank have increased in size and initiate migration and bridges through the city perimeter. This can be seen in dark red regions in **Figure 4 and Figure 5.**

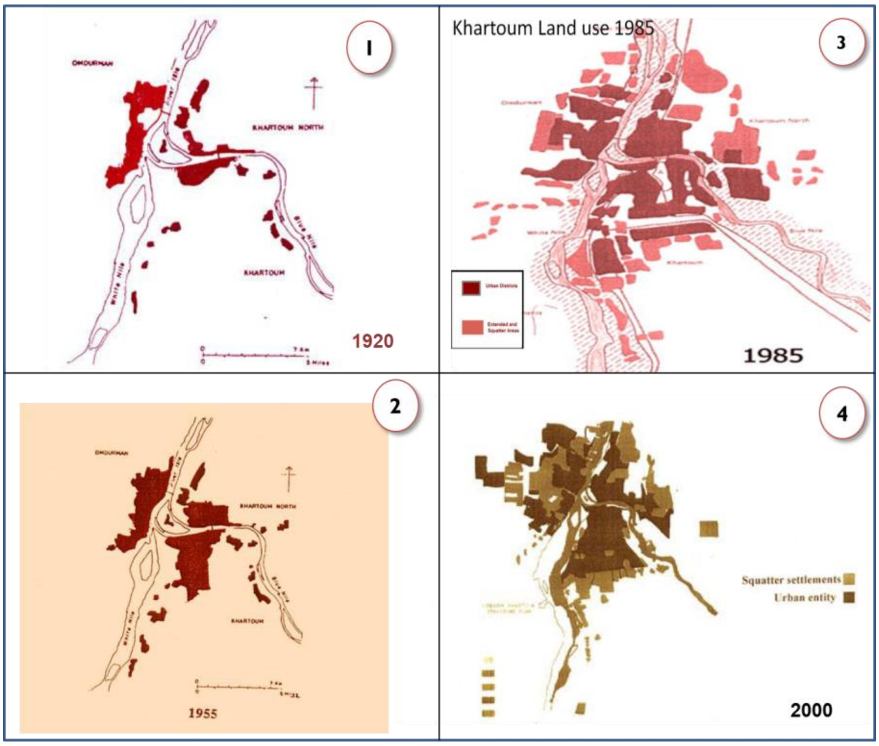


Figure 4 – Khartoum Land use from **1955 -2000**

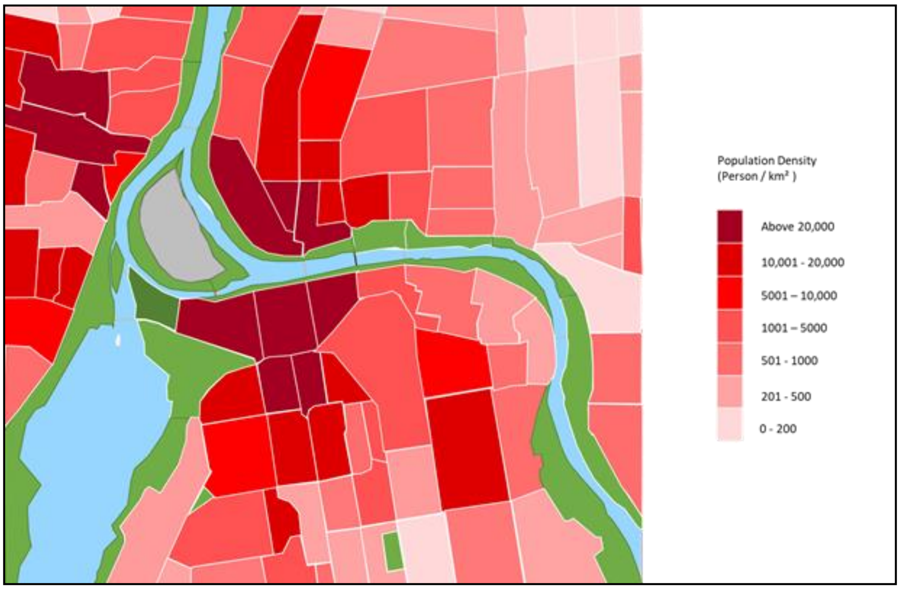


Figure 5 – Khartoum Population Density 2022

1.2 Khartoum Mobility Data

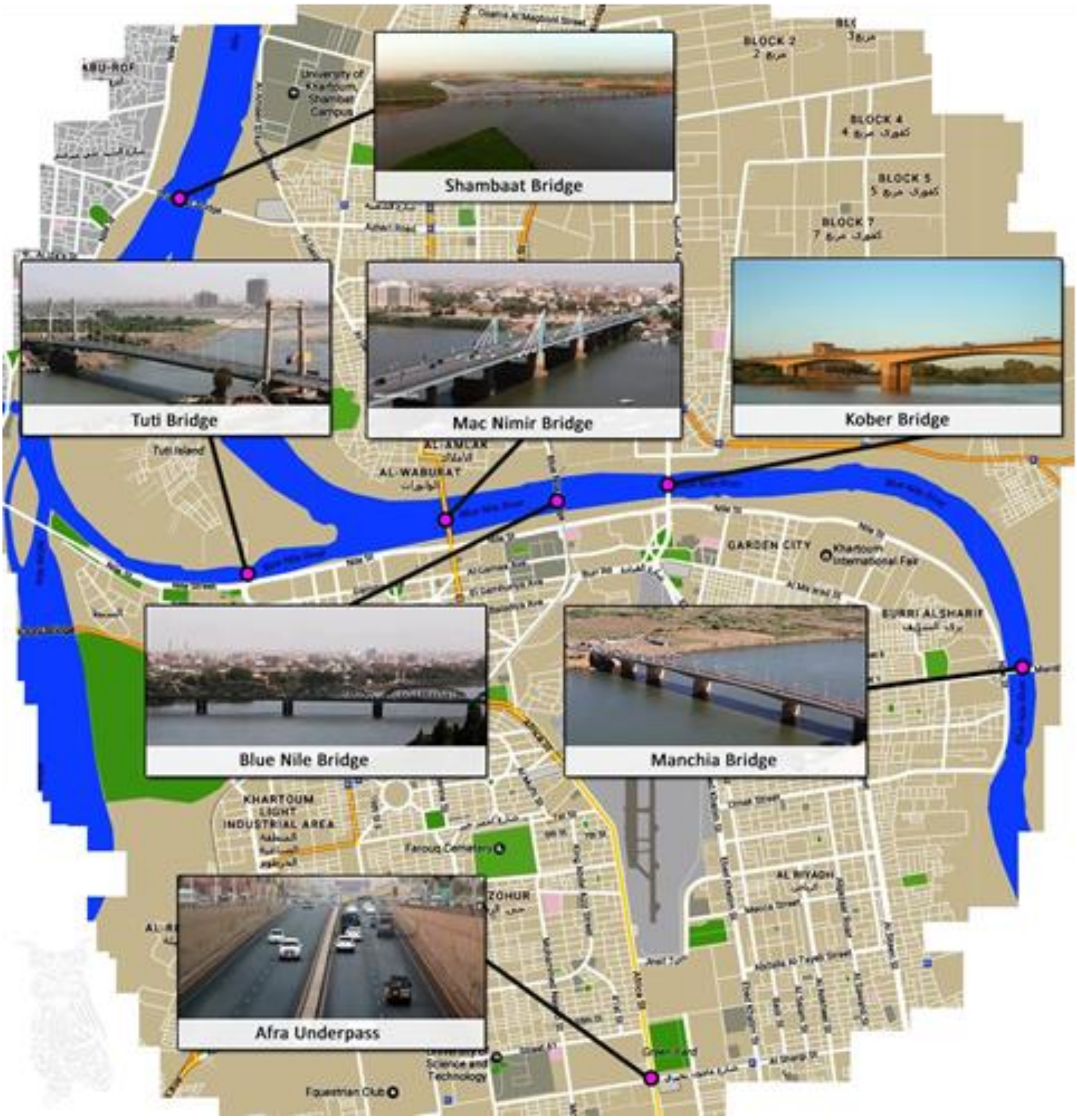


Figure 6 – Bridges across Khartoum Metropolis

1.3 Khartoum Mobility Data

There are approximately 4 million passenger trips per day, of which 2,865,080 trips are required to be covered by public vehicles.

According to studies carried out in 2015, the percentage of passengers using public transport compared to private transport was 70%.

Table 1: The number of daily passengers' trips in the designated year

Year	Passenger Trips in a Day	Passenger Trips in a Day using public Transport
2010	3,087,524	2,161,267
2015	4,092,297	2,865,080
2025	5,425,840	3,798,088
2035	9,562,137	6,693,496

Table 2: Public vehicles and numbers of passengers in Khartoum state/day in 2005

Type	Licensed	No. of Trips	No. of passengers/trip	Total No. Of passengers
Civil buses	69	8	50	27,600
Tourist buses	89	8	50	35,600
Mini-buses	7705	8	25	1,541,000
Taxi	96	8	7	5,376
Medium	2203	7	7	107,947
Total				171,523

Table 3: Number of passengers Travelling per Day in 2015 to Khartoum, Khartoum Bahri and Omdurman Centres.

Region	Bus (25 passengers) On average	Number of trips per Bus per Day	Total Number of Buses	Number of Passengers Travelling per day
Khartoum	3,337	409	38,382	959,550
Bahri	392	67	3,398	84,950
Omdurman	759	92	6,006	201,750
Total				1,246,250

Table 3 shows the estimated number of vehicle trips heading towards the main centres of Khartoum, Khartoum Bahri and Omdurman and the number of passengers moving during an average day in 2015. It indicates that one and a quarter million (1,246,250) passengers per day move towards the main urban centers and this number represents more than 43% of the total number of passengers travelling using public vehicles.

1.4 Vehicle Data in Khartoum

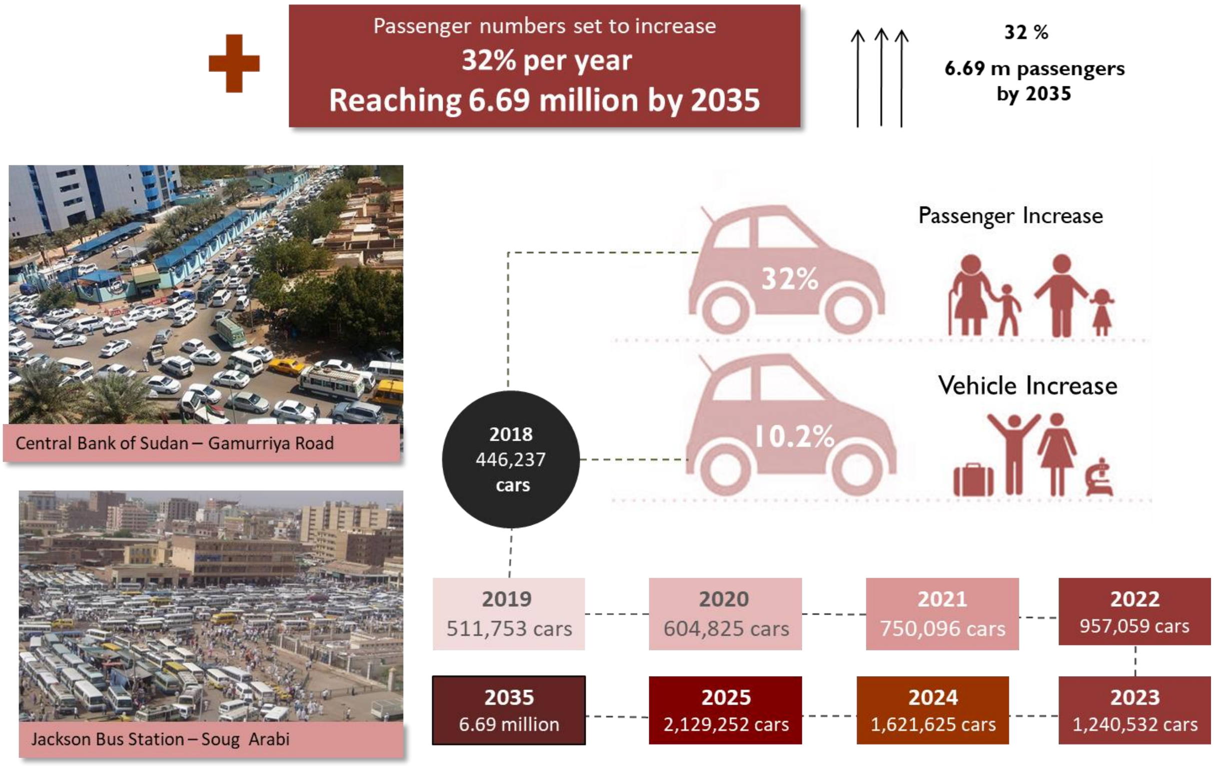


Figure 7 – Vehicle projected increase

From the latest Khartoum Transport and Mobility Study, it is estimated Khartoum traffic need in 2015 as more than 4 million passengers' trips per day, of which 2,865,080 trips are required to be covered by public vehicles as provided in Table 1. The percentage of passengers using public transport compared to private transport was 70%.

In comparison, the number of passengers using public transport and travelling throughout Greater Khartoum in 2005 was far less than the 2015 figure (42%) as exhibited in **Table 3**. This is of course obvious because of the rapid population growth.

2.0 Transportation Policies building on data

Transport policymaking for the Khartoum city region is led by the Ministry of Infrastructure and Transport, The Ministry of Transport and the Roads and Drainage Authority working across Khartoum, Omdurman and Bahri.

Evolving transport policies need to be fully aligned with the existing and emerging spatial development strategies. These strategies will guide the implementation of mixed-use regeneration projects on inner city brownfield sites and substantial housing and employment developments in suburban and peripheral locations, both within and outside the city boundaries.

The Khartoum city region will experience substantial growth during the next 10-15 years - driven by its dynamic economy and central government pressure to meet housing delivery targets. Thus, urban regeneration and expansion will have a major impact on future patterns of passenger demand and without an effective rapid transit system it will not be possible to manage this growth, in a way which will significantly reduce current levels of congestion and pollution.

2.1 Road Side Survey Data

In 2014, a survey was carried out along 38 locations on the roadside and carried out 19,152 interviews in six intervals of one hour each and for each running direction. The following information have been collected:

- vehicle type and number of passengers for each vehicle, and
- origin and destination of the journey, purpose and duration

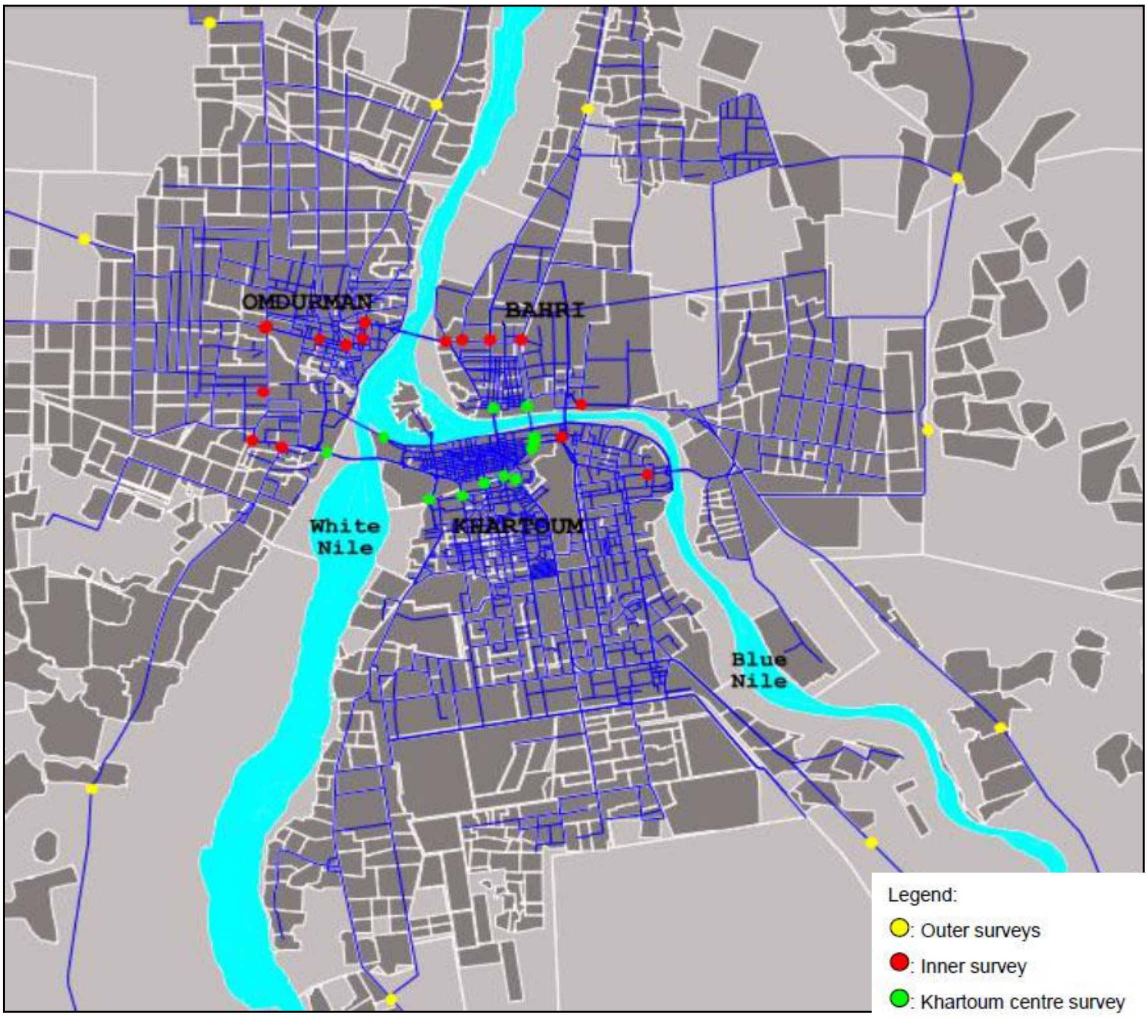
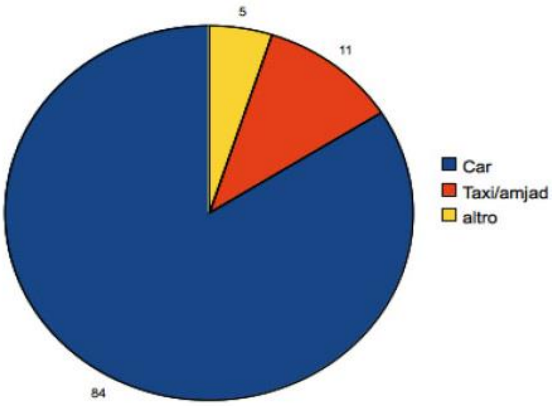


Figure 8 – Survey locations

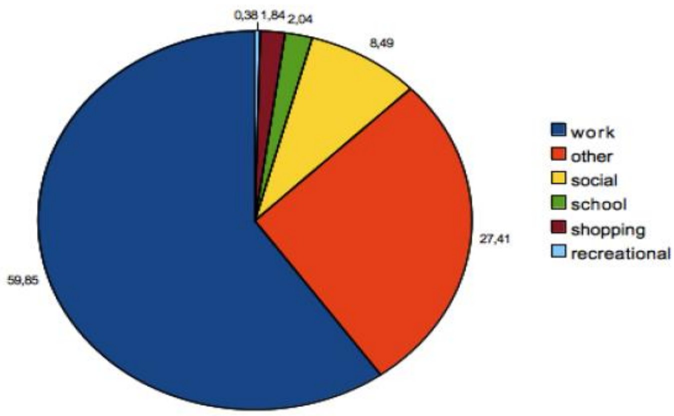
2.2 Road Side Survey Data Maps



The 84 percentage of the vehicles is represented by private car. On average, the number of people recorded per vehicle is:

- 2,87 people/car
- 2,52 people/taxi_amjad

Figure 9 – Composition of Traffic



- Almost 60 percentage of interviewees declared that the purpose of their journey is related to work reasons.
- The 27 percentage of the people declared “other” purposes for their journey.
- More than the 8% of interviewees declared to move for social reasons.
- Only the 2% of the people stated a journey purpose related with education (school).

Figure 10 – Journey Purpose (%)

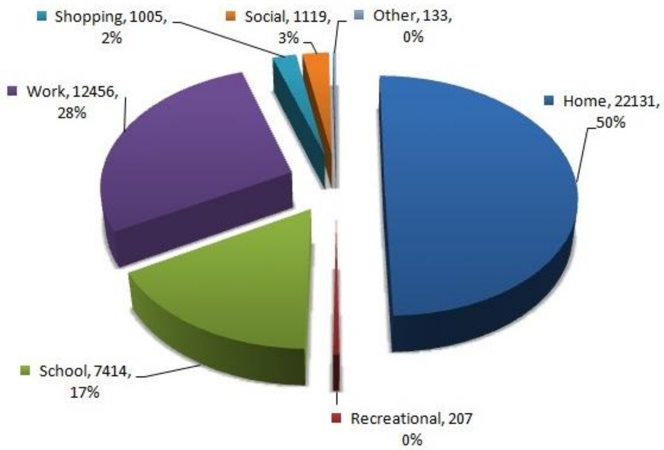


Figure 11 – Population Mobility indicators in Khartoum State. Source: MEFIT 2015

Within the context of the Roadside survey, data collected in the Mobility Study also shows information about origin and destination of the trips.

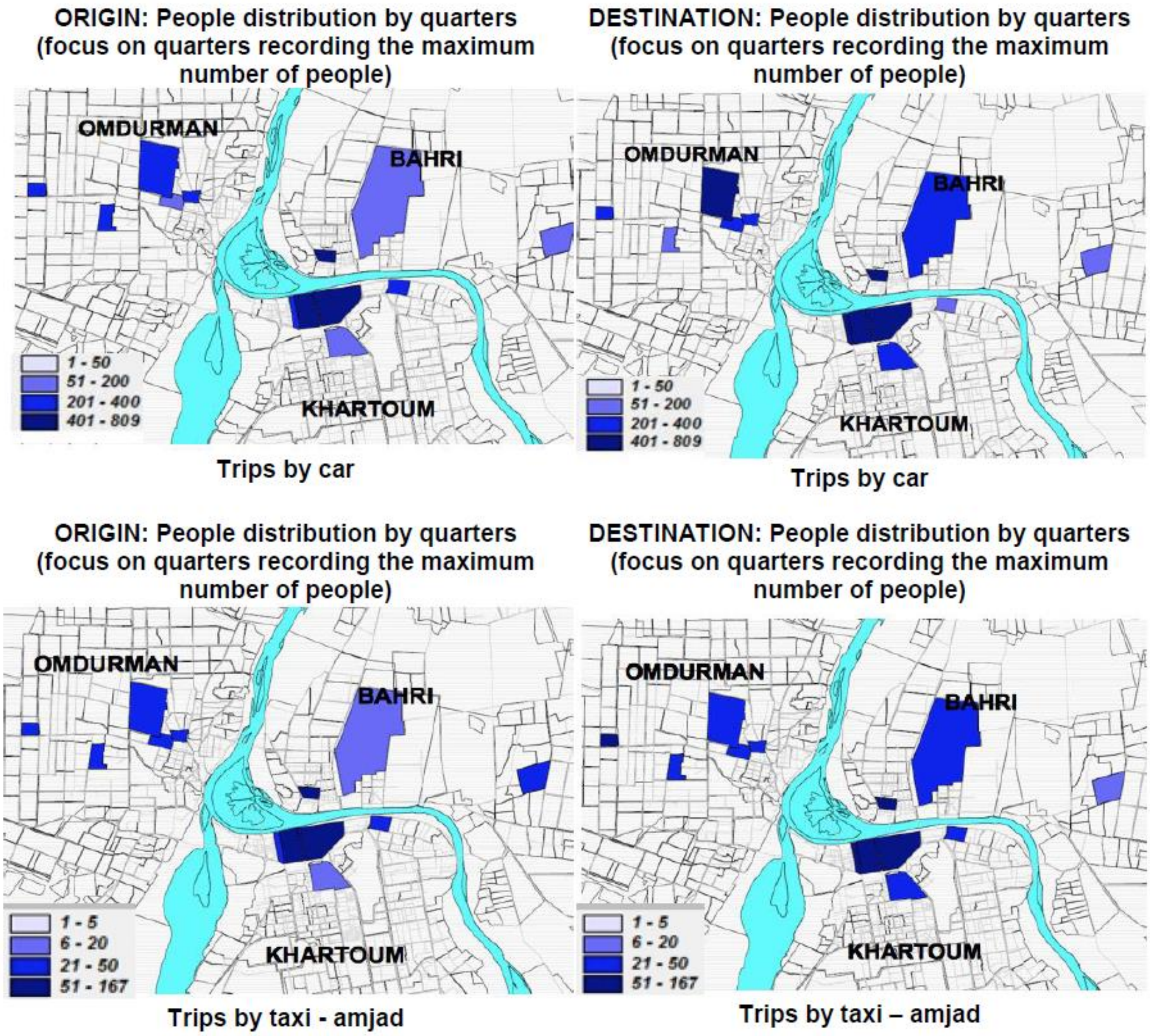


Figure 12 - Origin/Destination distributions

The total number of surveyed trips (Figure 12), with private car, outside the origin quarter, is 15,974. The maximum number of trips between the origin and a destination monitored during the survey is 29 (0.2% of the total, corresponding to about 3,500 trips / day).

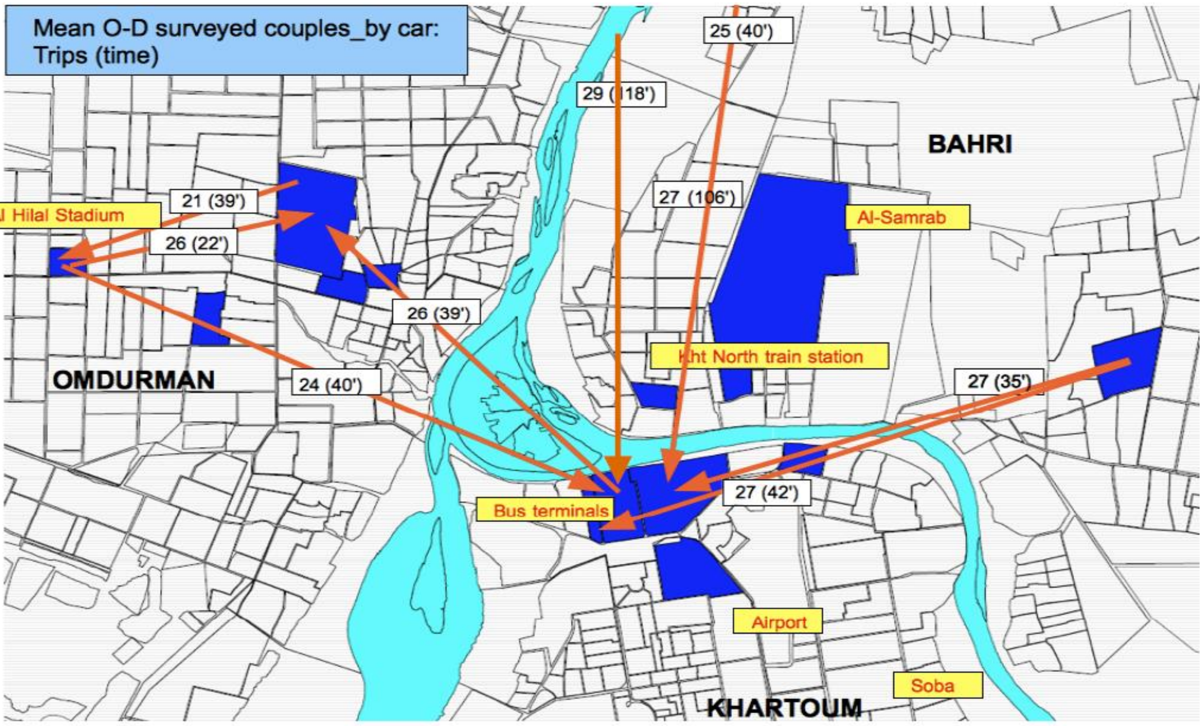


Figure 13 - O/D couples with highest number of trips in Roadside surveys

Legend:

White boxes: counted number of trips per day with private car and declared travel time. : Trip running direction

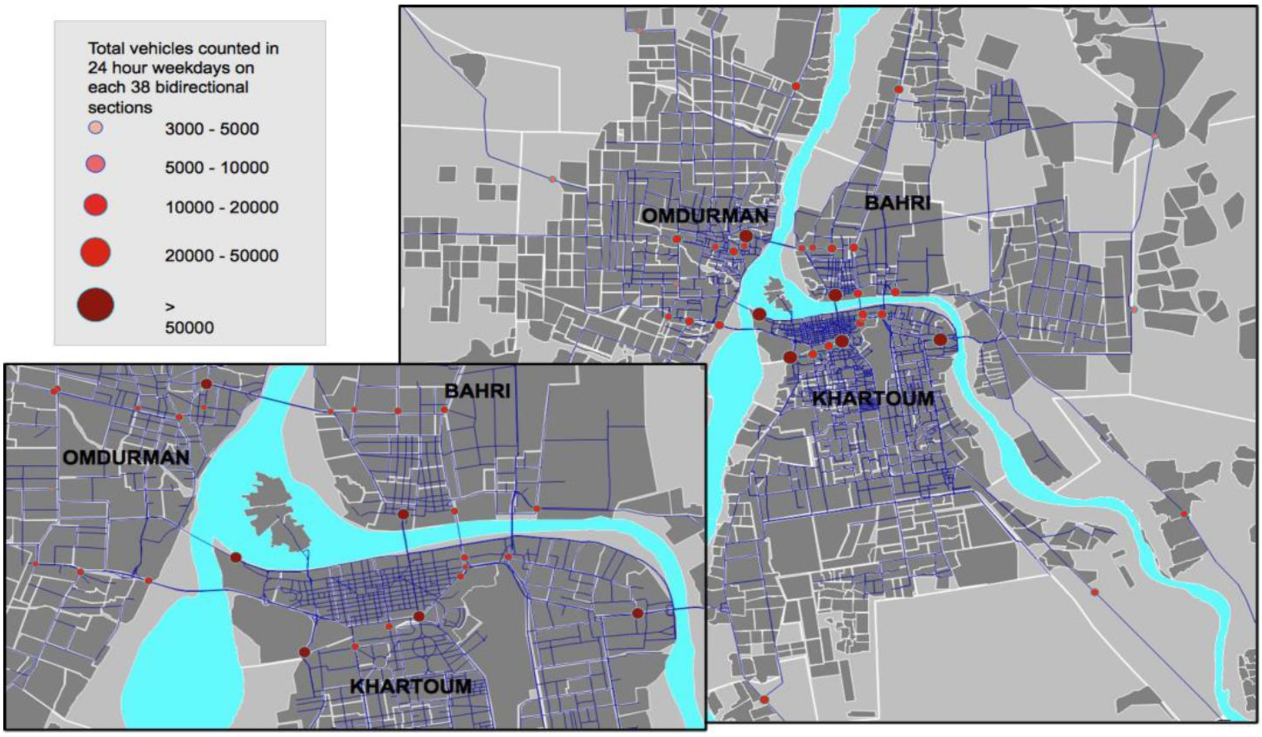


Figure 14 - Locations of counting sections

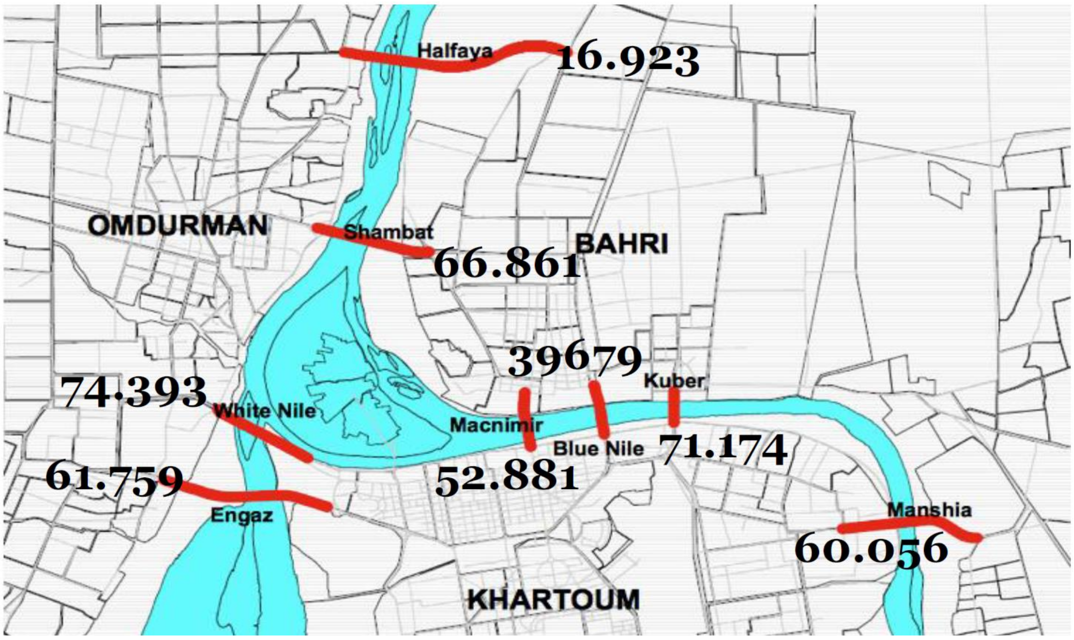


Figure 15 Daily flow of vehicles recorded across the bridges (8 bidirectional sections)

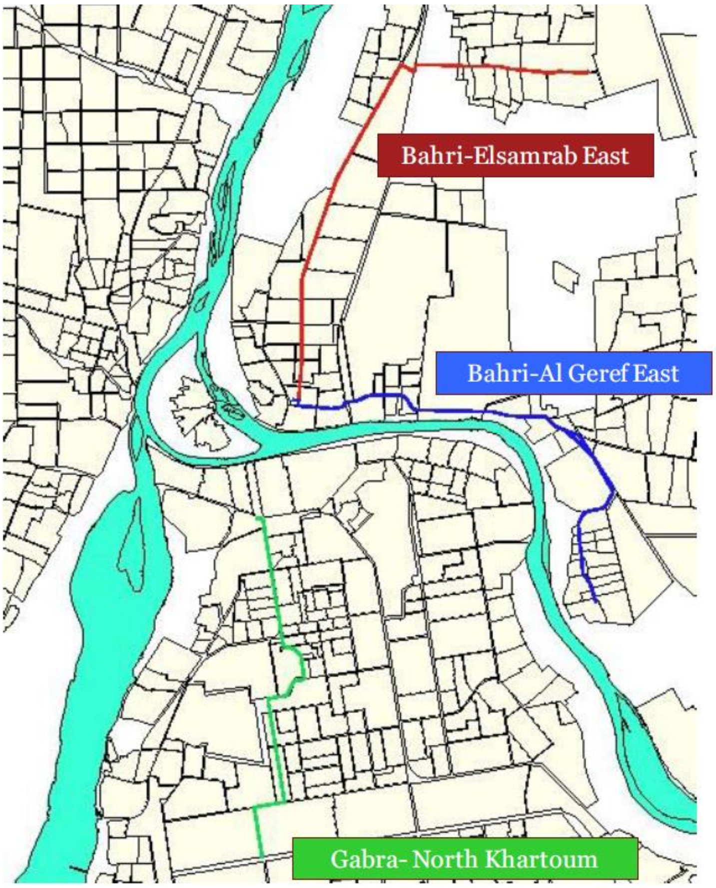


Figure 16 - PT lines with highest number of incoming passengers (07:00-08:00 a.m.)

The following figures show the sum of on-board passengers observed on all the transport public services, which operate on each link. Links are coloured with different colours and thickness, as shown in the legend, in basis of different number of detected on-board passengers.

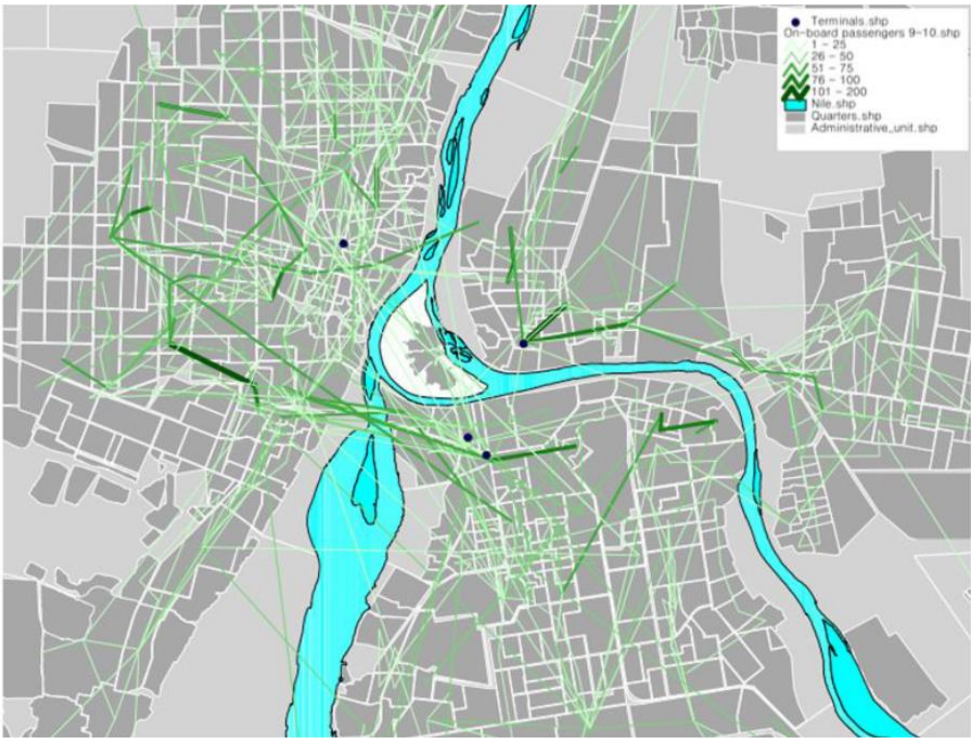


Figure 17 – Sum on-board passengers per link (09:00 – 10:00 a.m)

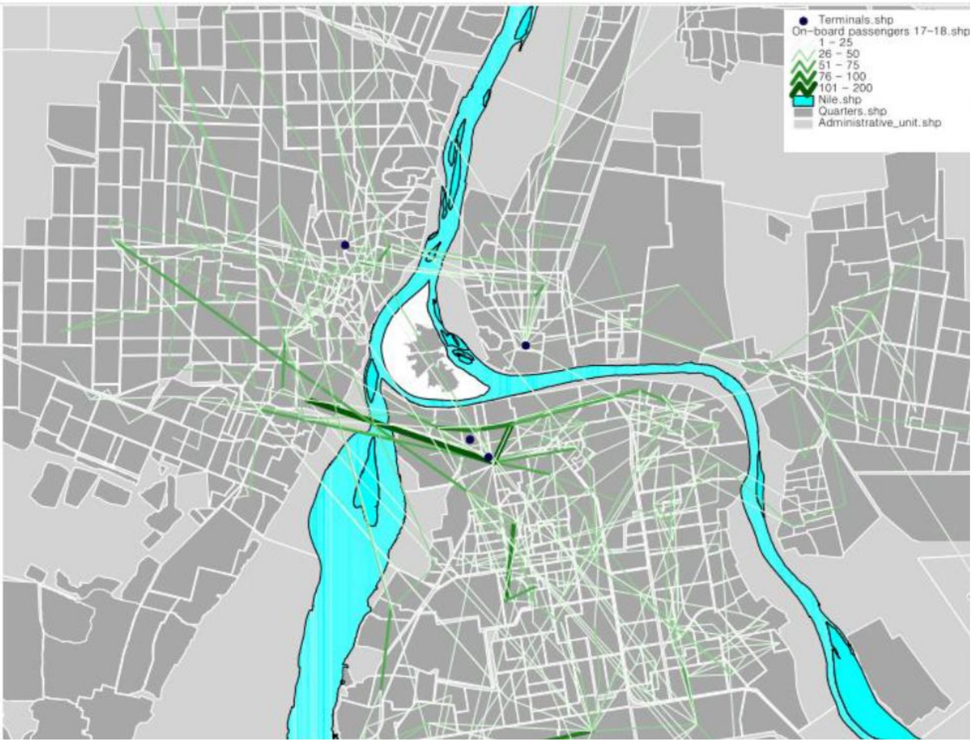


Figure 18 - Sum on-board passengers per link (17:00-18:00 a.m.)

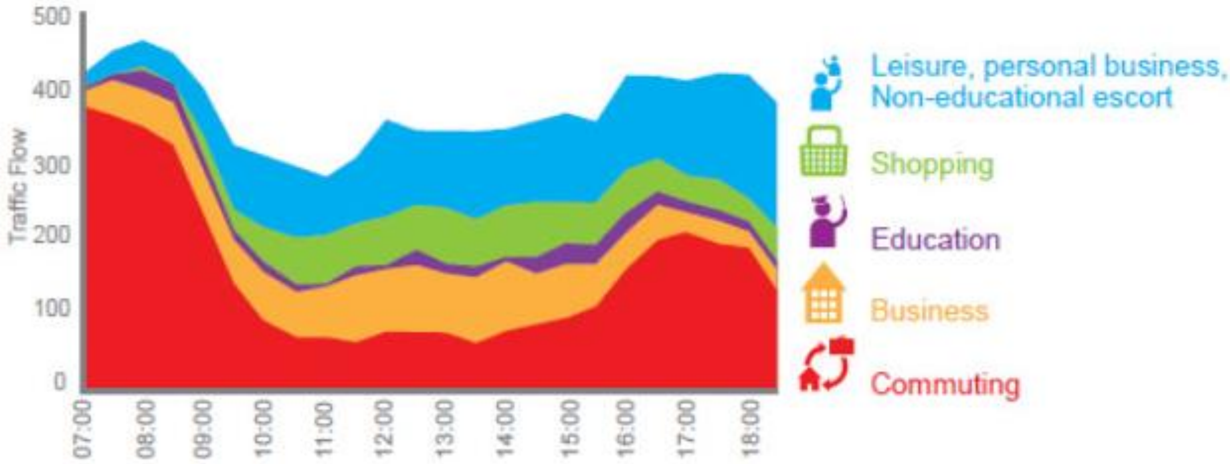


Figure 19 – Purpose of Trip

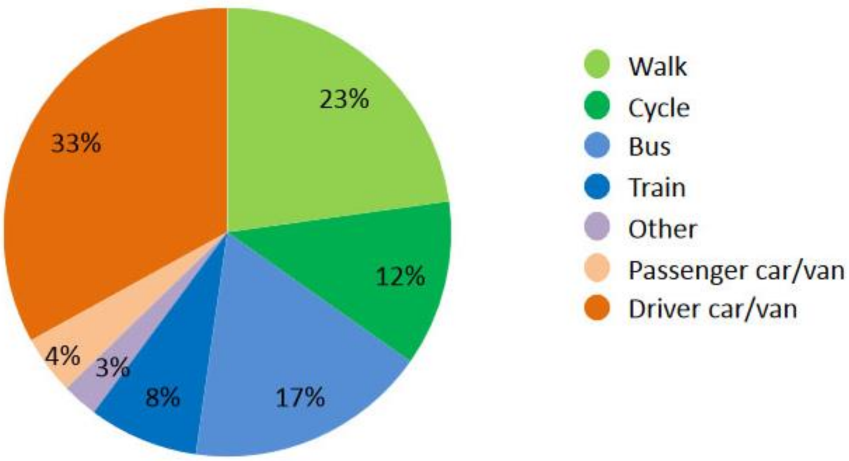


Figure 20 – Initial Mode of Transport (%)

2.3 Household survey overview

The Khartoum State includes seven localities with an estimated population of 7 million people. The majority of the population is concentrated in the Capital, Greater Khartoum with a population of 5.8 million of people. Furthermore, Greater Khartoum includes three towns, Khartoum city, Omdurman and Bahri. The following figure shows the seven Localities composing Khartoum State.

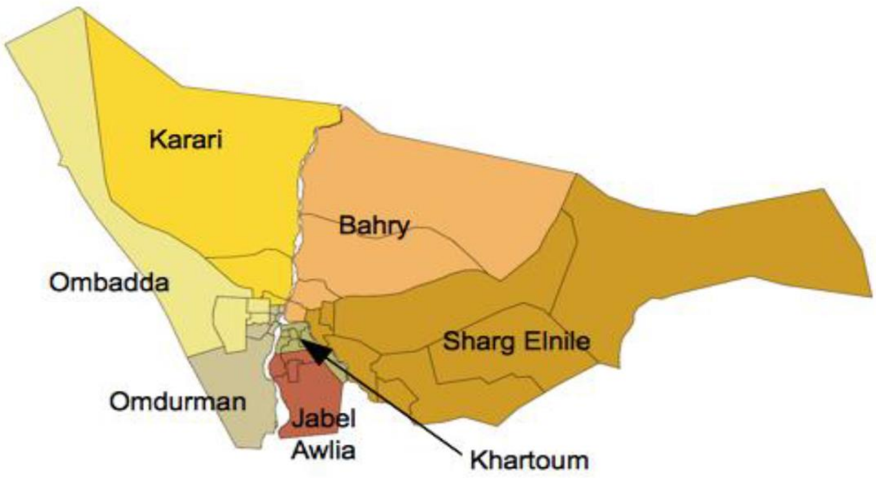


Figure 21 – Regions of Khartoum State

The household survey carried out in all the seven regions provided the following results. The following figure shows the number of interviews carried out in each region. In Figure 22, the percentage of surveyed householders in one region relative to all Regions is highlighted in red.

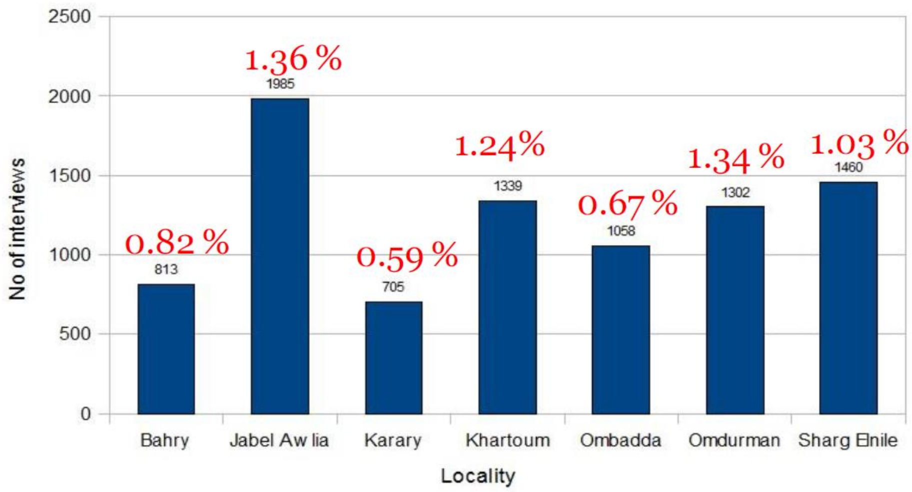


Figure 22- The percentage of surveyed householders

Furthermore, Khartoum includes 1.345 quarters, with an average population of around 3.800 people per quarter and an average density of about 83 people per hectare.
The following figure shows the density per quarters.

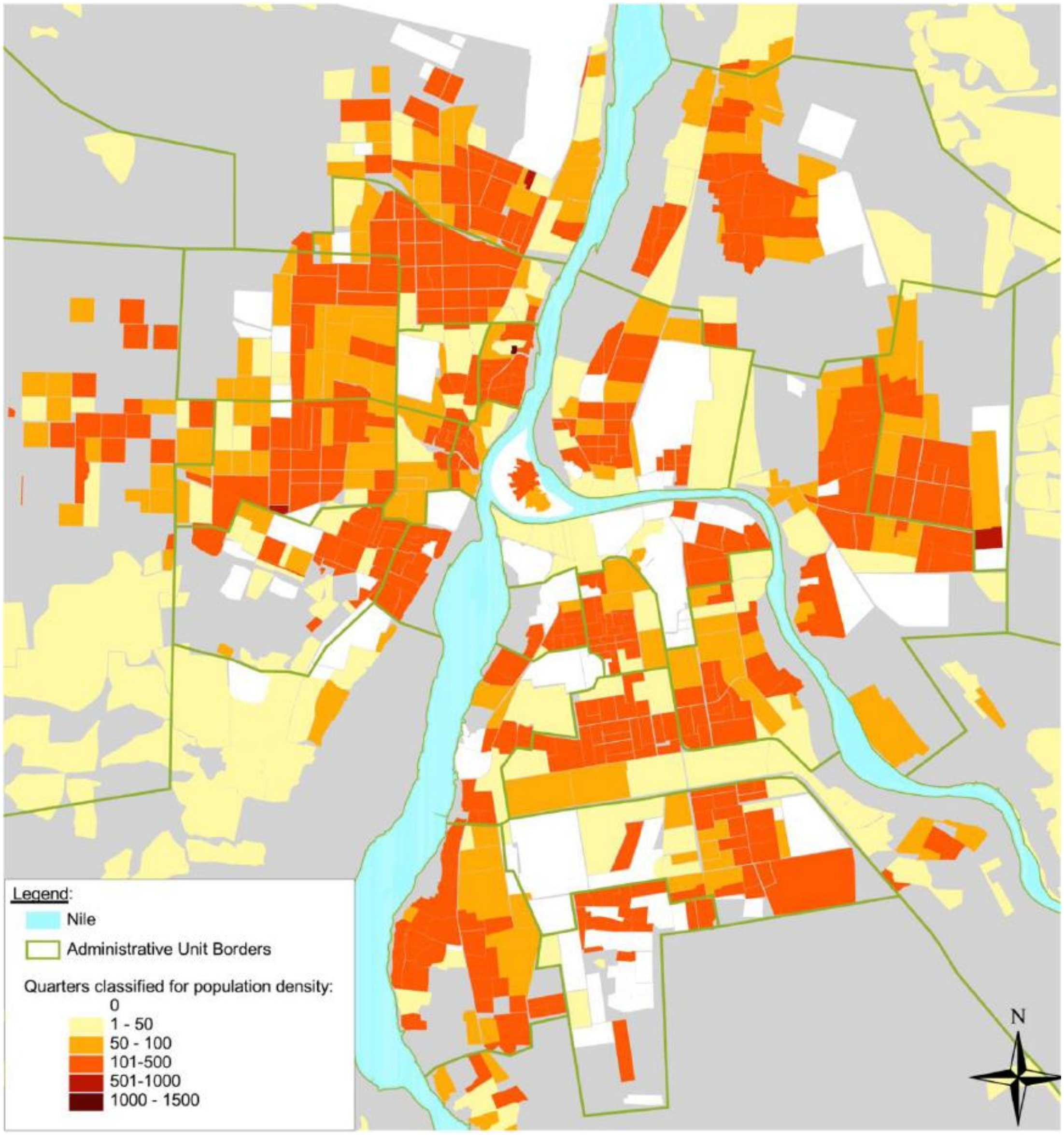


Figure 23 – Khartoum population density per square quarters

The priority to invest more in infrastructure comes at a time when many African governments are highly indebted and face competing calls on their scarce resources.

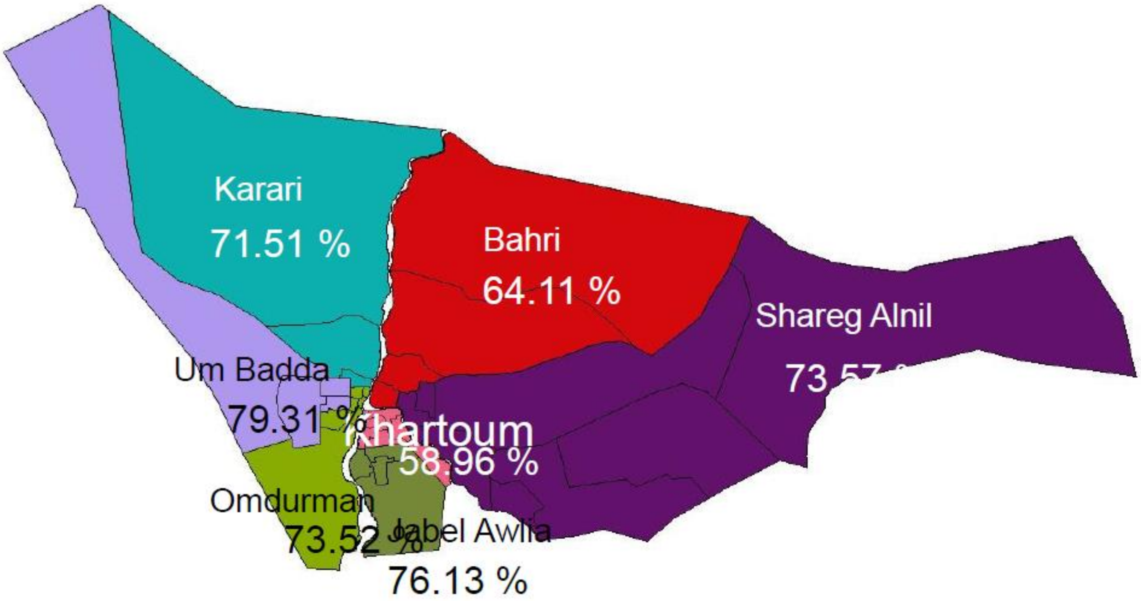


Figure 24 - Lack of car ownership by Locality

Figure 25 - O/D couples with highest trips number

2.4 Journey's purpose and length of the trip

As for the journeys' purposes (Figure 26), approximately 50% of records refers to the type 'Home'; while about 28% registers 'work' as type of journey followed by 'school' (16.7%).

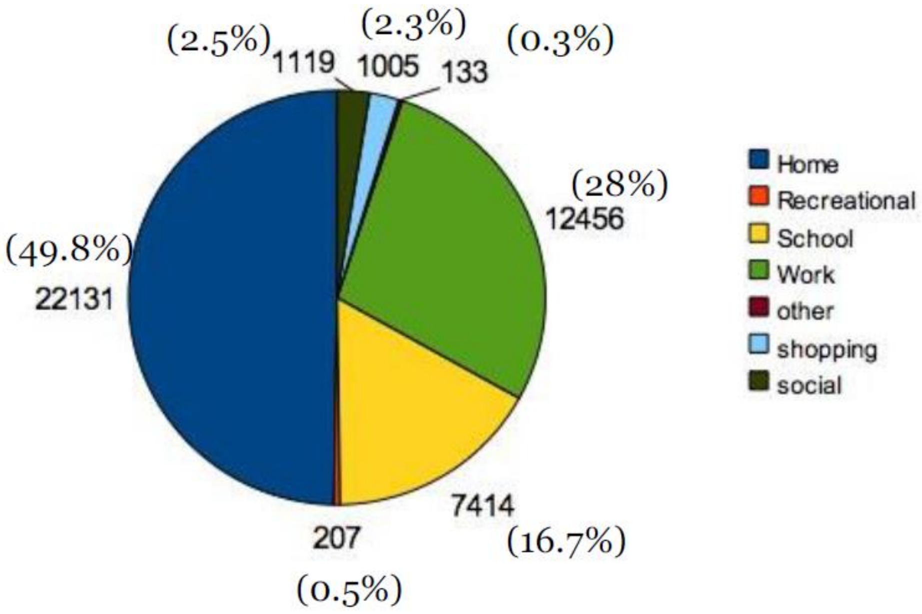


Figure 26 - Journey's purpose

On average a journey requires **37 minutes** with significant differences according to the hour time. As shown in Figure 28, longer trips are recorded in early morning (4:00-6:00) and at night (20:00- 23:00)

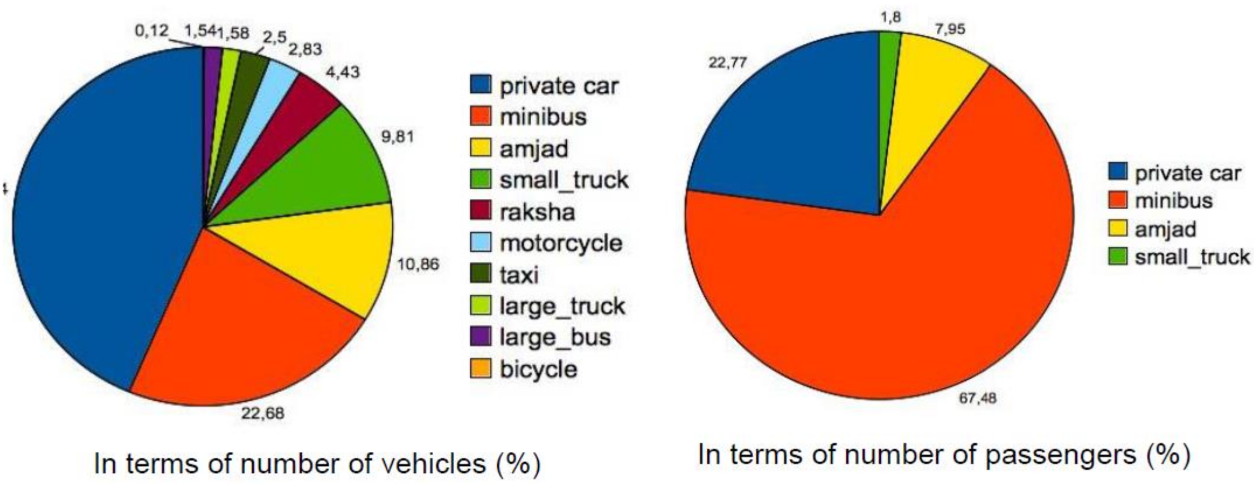


Figure 27 - Modal split in traffic counts (%)

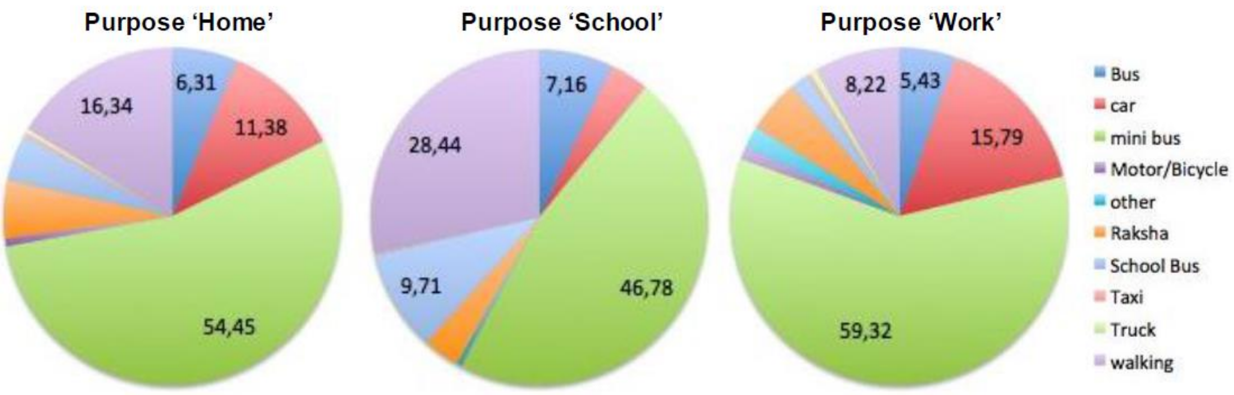


Figure 28 - Modal split for trip purpose (%)

As for the number of trips, there is a peak in the morning at 7:00. In the afternoon, there is a peak equally distributed during 16:00-17:00.

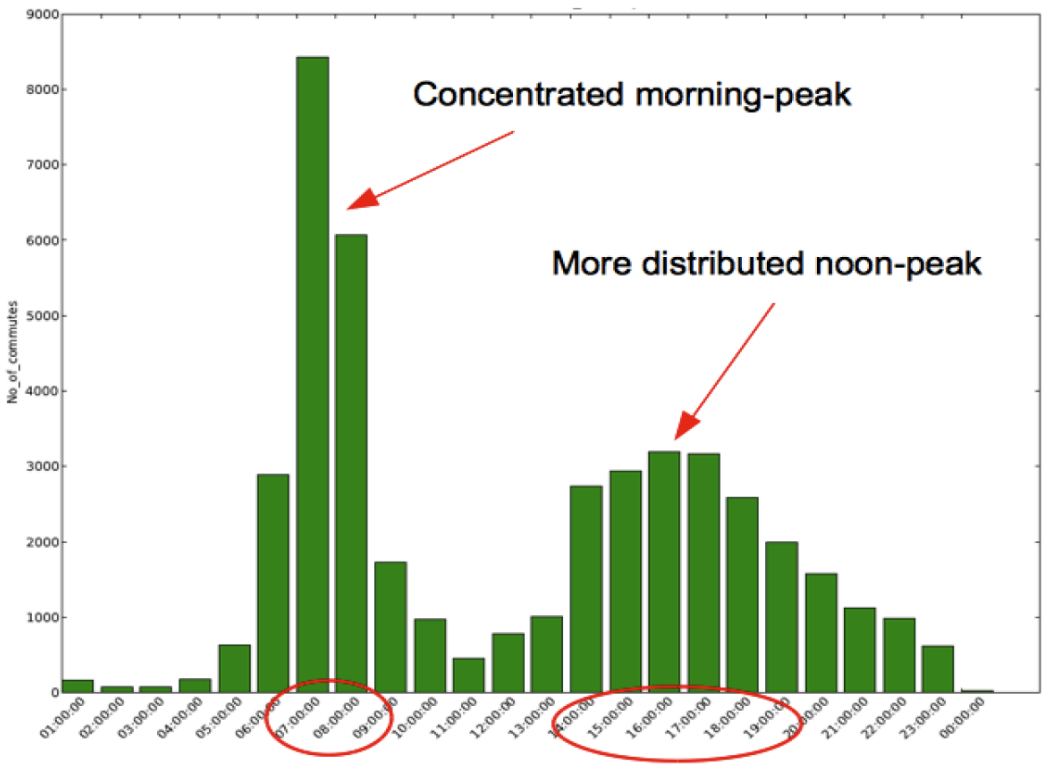


Figure 29 – Number of Trips

2.5 Destination of population movements

The studies have shown that the primary function of the public transport service lines provide transport links between homes and the workplace while the other connect the institutions of learning.

From the questionnaire who were asked about their destinations:

- 50% said going home,
- 28% were going to work and
- 16.7% were school students heading for schools and universities.

Other trips are for social gatherings, shopping and recreation.

2.6 Traffic Analysis Zones (TAZ)

Traffic Analysis Zones represent homogeneous area and have been defined by the aggregation of households and buildings.

The basic elements aggregated are the 1.345 quarters of the State of Khartoum, which have been grouped in 338 TAZ taking into account the following two criteria:

- the quarters out of the city of Khartoum have been aggregated in huge zones, depending on the approaches to the city;
- the inner quarters have been aggregated on the basis of population in smaller zones.

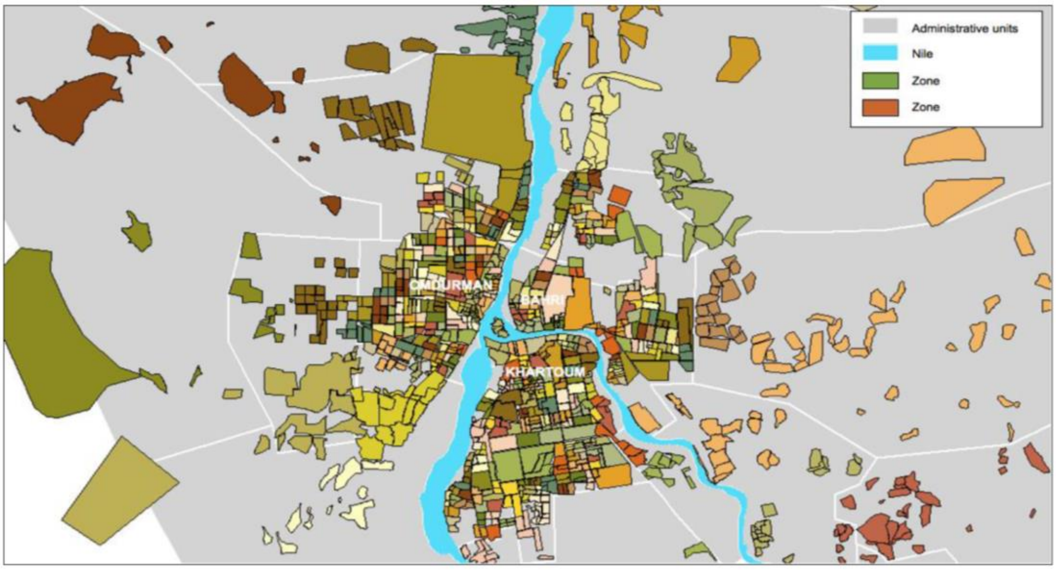


Figure 30 – Traffic Analysis Zones TAZ

2.7 Road network

The first road network included in the model was a 2014 network, consistent with the household surveys, roadside surveys and special surveys carried out in summer 2014.

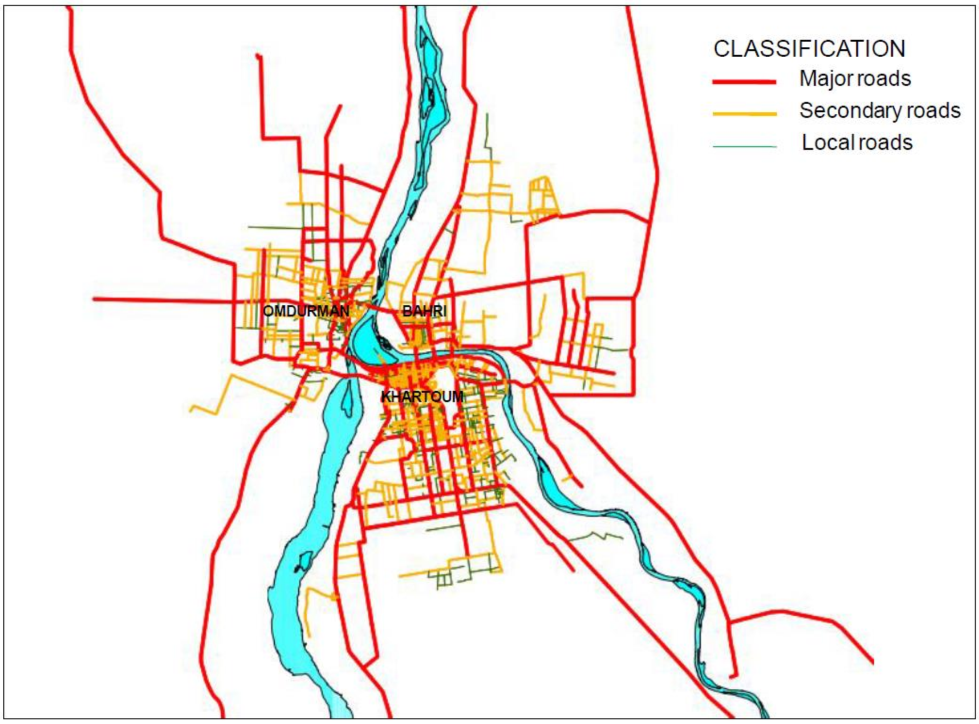


Figure 31 - Road network 2014 – functional classification

At the beginning of January 2011 Halfaya Bridge was opened: this link was not included in the first road network so it was built another network with this bridge.

Both networks have been classified in 3 functional classes:

1. Major roads 2. Secondary roads 3. Local roads

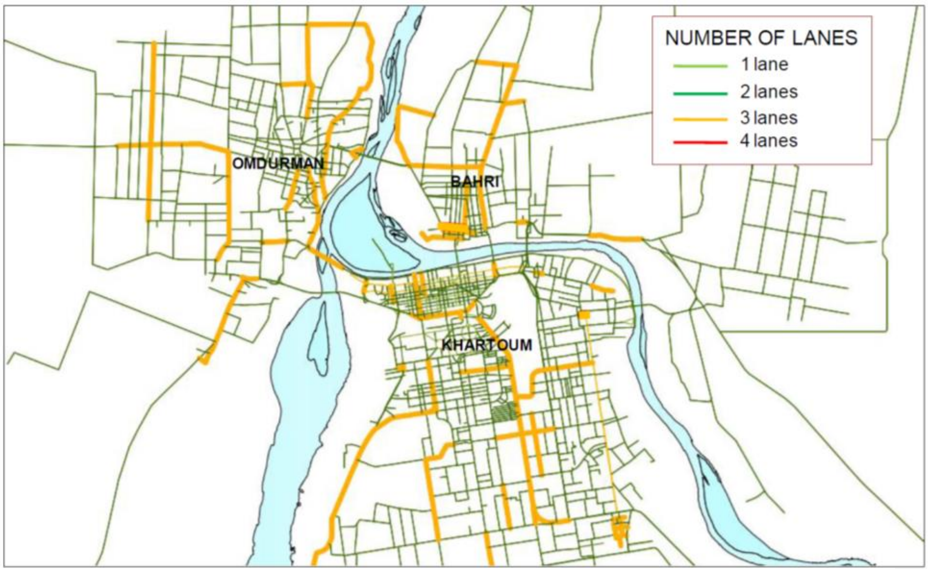


Figure 32 - Road network 2010 – number of lanes

There are 1723 km of paved roads and 170 km of unpaved roads.

2.8 Main Routes across City

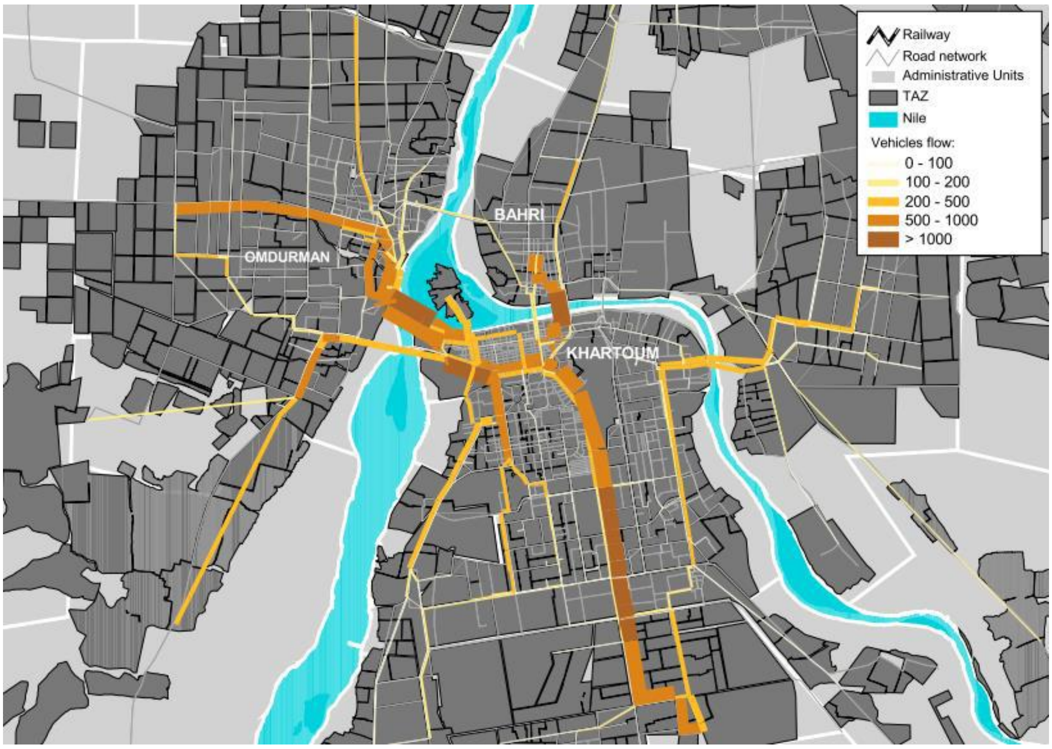


Figure 33 - Road network: assignment of morning peak hour (9-10) private matrix –

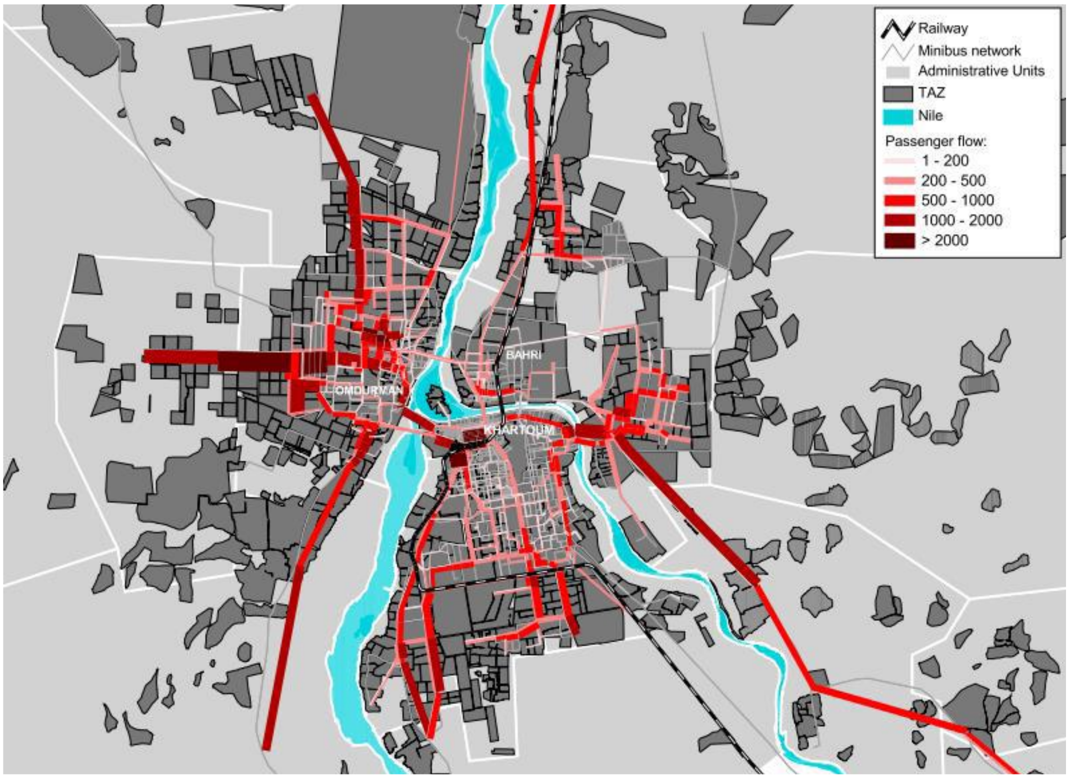


Figure 34 - Minibus network: assignment of morning peak hour (9-10) public matrix

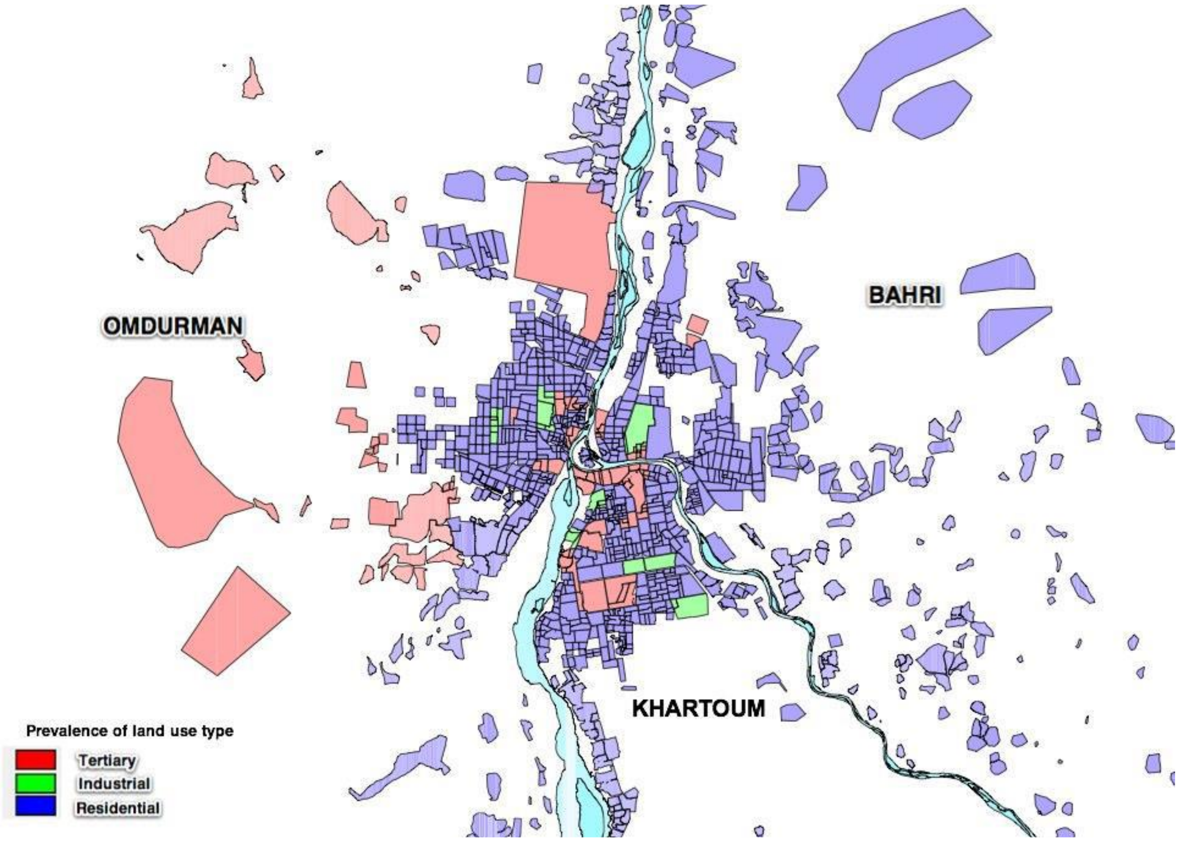


Figure 35 - Land Use in Each Zone

The expression of utility function *Vi* for each alternative (destination *i*) is:

$$Vi=\beta tertTerti+\beta indIndi+\beta resResi+\beta sch\_hospSch\_Hospi+Availi$$

Road usage See **Figure 36** Road network**:** assignment of morning peak hour private matrix – saturation.

From the public assignment during the morning peak hour is possible to notice four main routes approaching to the city, from north-west, west, south-west and south-east. These are preferential directions to get to the central part of the city, Omdurman and North Khartoum.

2.9 Road Usage

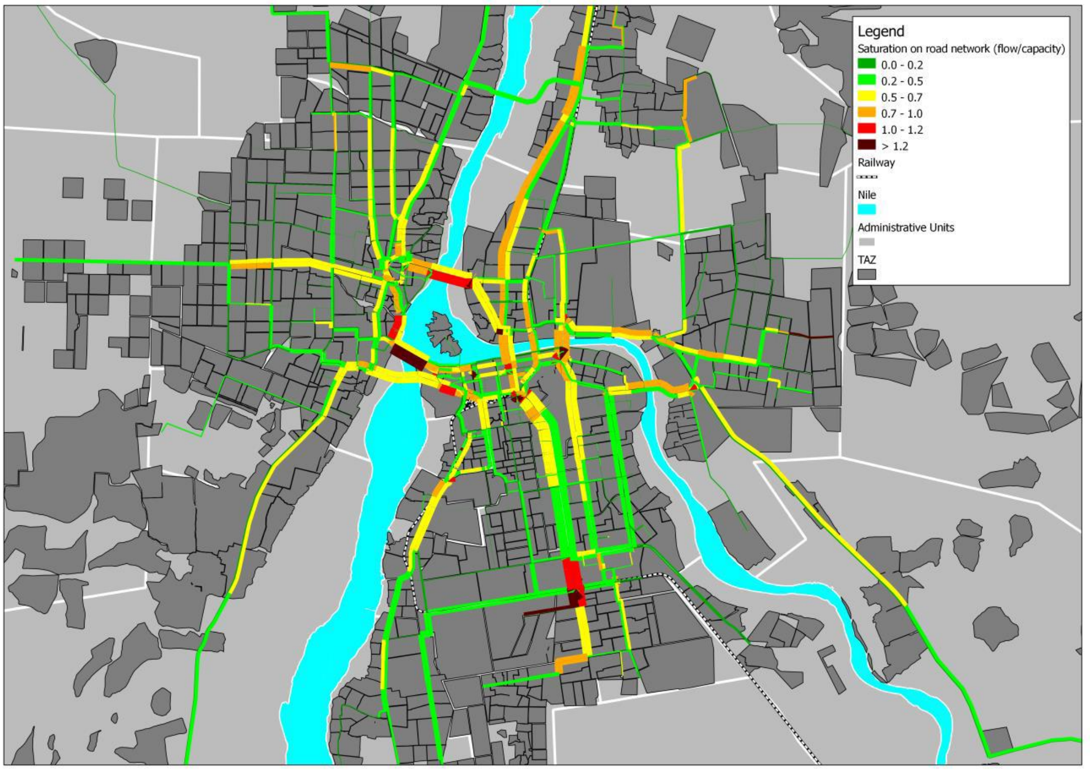


Figure 36 - Road network: assignment of morning peak hour private matrix – saturation

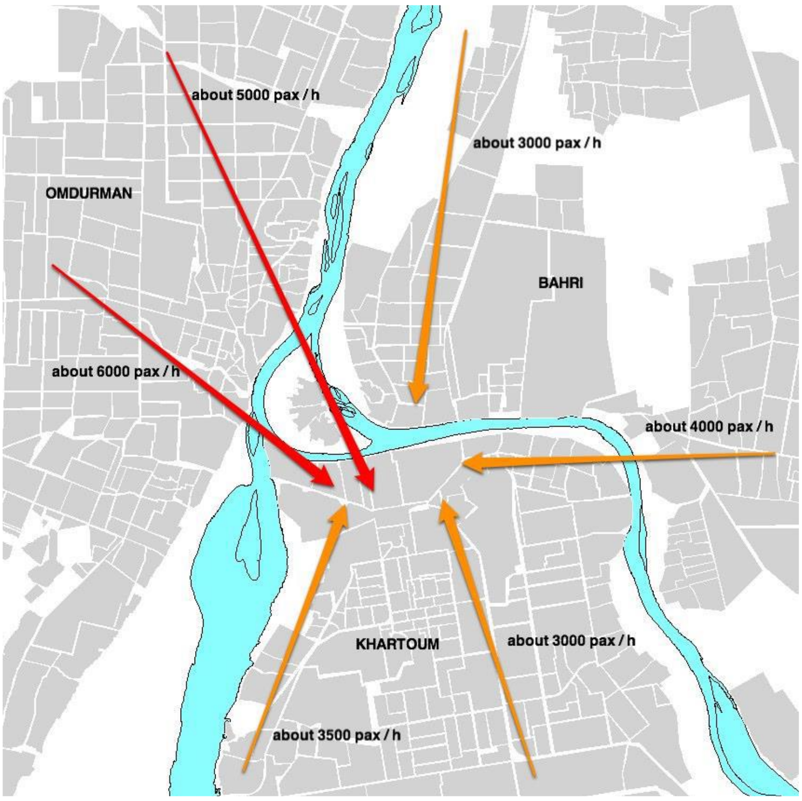


Figure 37 - Main directions for public transport in the morning peak hour (in terms of max per hour)

3.0 Why Light Rail and Trams for Khartoum

Large-scale switch from car journeys to relieve congestion – to buses or trams or both?

The need to drastically reduce the number car journeys to reduce congestion and along popular routes and destinations as can be seen from Figure 13. This will add significantly to the longer standing argument that reducing car journeys is the only realistic way to reduce traffic congestion, which worsens fuel consumption, increases air pollution, and has serious negative economic and social impacts.

The interlocking environmental, economic, and social consequences of car dependent movement in the Khartoum city region are increasingly unsustainable: high levels of fossil fuel consumption and toxic air pollution, congested roads and long journey times with their negative impacts on the city's economy, unequal access to reliable and affordable travel opportunities and low levels of active travel.

This legacy of 20th century car-based city development can only be dealt with by making car travel the least attractive option rather than the first choice for most urban journeys.

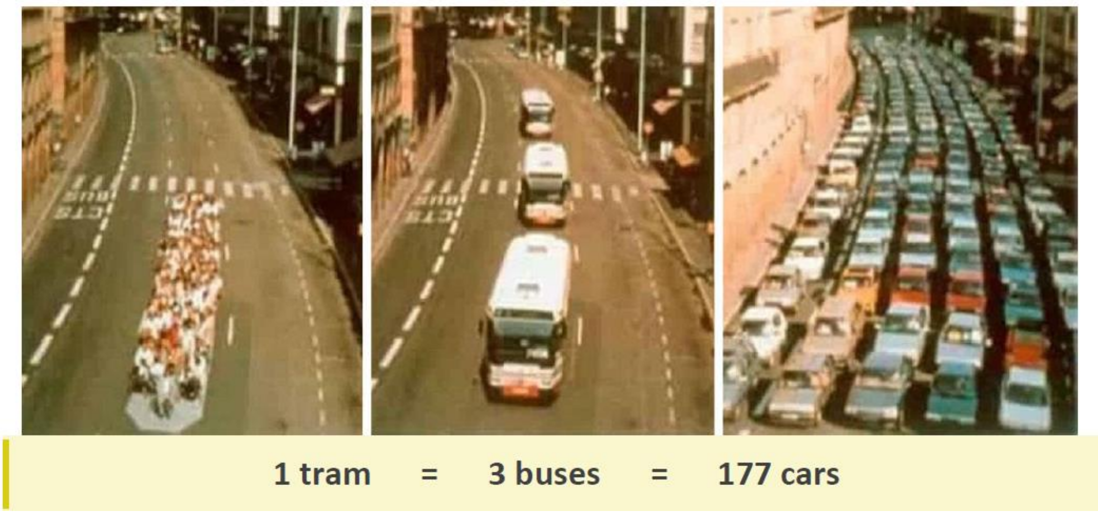


Figure 38 - Trams use road space more efficiently than buses or cars

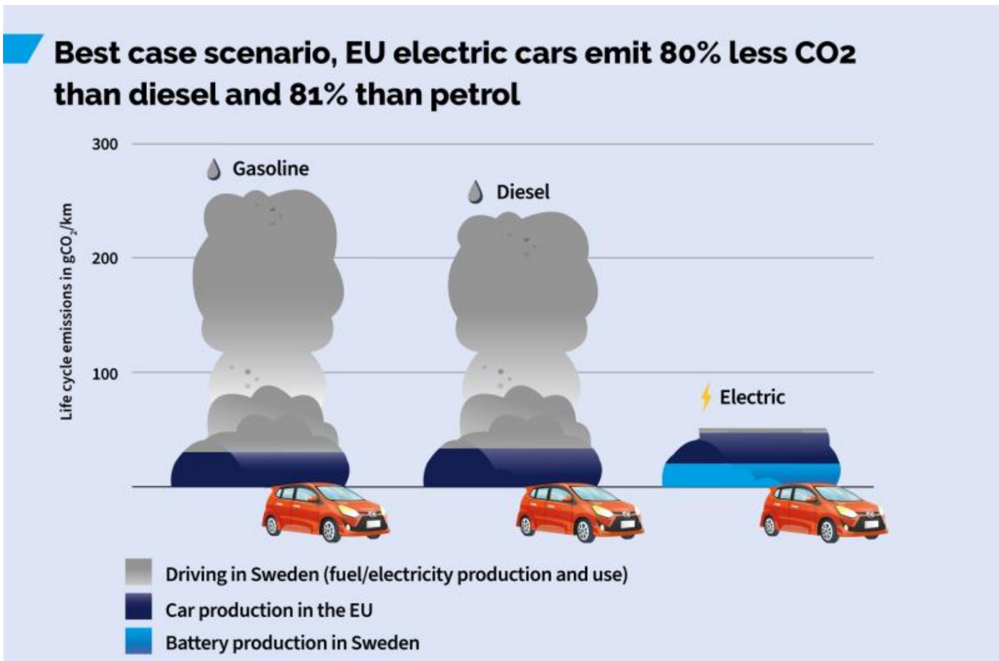
3.1 The rapid transit challenge

The creation of an integrated public transport system is an unavoidable necessity if people are to be persuaded to leave their cars for most trips. The experience of other cities provides evidence that a successful public transport network must be framed around a rapid (mass) transit system which:

- can move large numbers of people on journeys within the city and the wider city region;
- can run separately to other traffic;
- could include several different modes of transport - tram, train, and bus; and
- could run both overground and underground.

The key strategic transport policy issue facing Khartoum is the choice of the mix of public transport modes which will most effectively deal with the following range of contemporary urban issues.

In global health terms it is now widely understood that an effective response to the climate emergency requires the elimination of the fossil fuel consumption of the internal combustion engines used in cars, buses and other vehicles, which threatens the planet by generating tail pipe carbon dioxide (CO2) emissions.



3.2 Destination and Frequency of Population Movements

It is estimated Khartoum traffic need in 2015 was more than 4 million passengers' trips per day, of which 2,865,080 trips are required to be covered by public vehicles as provided in Table 1. The percentage of passengers using public transport compared to private transport was 70%.

In comparison, the number of passengers using public transport and travelling throughout Greater Khartoum in 2005 was far less than the 2015 figure (42%) as exhibited in Table 2. This is of course obvious because of the rapid population growth.

Table 3 shows the estimated number of vehicle trips heading towards the main centres of Khartoum, Khartoum Bahri and Omdurman and the number of passengers moving during an average day in 2015. It indicates that one and a quarter million (1,246,250) passengers per day move towards the main urban centers and this number represents more than 43% of the total number of passengers travelling using public vehicles.

It is estimated that there are 2,306,721 passengers per day moving towards Khartoum's capital in 2022.

3.3 Why Tram Rapid Transit

In social terms there are issues:

- The need for lower income groups, an ageing population, people with disabilities, and people with babies and young children to have equal access to safe, reliable, and affordable travel - which provides better connectivity to jobs, schools, health and education facilities and to opportunities for leisure and recreation;
- The importance of eliminating 'travel poverty' caused by people spending a disproportionate amount of their limited income on congested, long journeys from the south of the city to poorly paid jobs north of the river.

Figure 39 - Reduction in traffic accidents - vehicle falls into trench

In public health terms there are three key issues:

1. Toxic pollution from tailpipe emissions – NOx, CO, PM10 and unburnt fuel;

2. The not yet widely understood, but increasingly urgent, need to reduce damage to public health by reducing both the toxic air pollution caused by Non-Exhaust Emissions (NEE) from rubber tyre dust and the volume of micro-plastics released from tyre abrasion which enters surface water and contributes to marine plastic pollution; and

3. The increasingly understood need to improve levels of active travel - walking, cycling, and scootering.

4. Steel Tram Lines will relieve some of the burdens of the frequently used roads which often deteriorate from wear and tear including the continuous exposure to over 40 C° heat and direct sunlight. The results of the deterioration become worst during rainy period when the road surface and under course become weared.

In economic terms there are two key issues:

1. **Congestion**, which worsens air pollution, results in unproductive time and exacerbates the inherent economic inefficiency of only one person per car, compared with some 70 passengers per bus and 200-300 in a tram; and
2. **Urban investment incentives** provided by the permanence of tram lines and associated political commitment, which supports regeneration at appropriate locations along their length within the city, and enables large-scale city extensions which are not car-dependent.

Figure 41 - Tram Line in Addis Ababa, Ethopia – supporting economic activity along route

This section now argues that the development of 21st century public transport system, structured around a tram - led rapid transit system, integrated with local rail services and orbital bus services supported by feeder bus routes, will deliver the most effective response to the transport challenges posed by Khartoum’s longstanding dependency on car travel.

3.4 Tail-pipe emissions and climate change

In 2019 an Air Quality Expert Group (AQEG) report to DEFRA on non-exhaust emissions radically updated scientific understanding of the toxic NEE air pollution generated by road transport, and its contribution to ambient particulate matter in the air associated with human ill-health and premature mortality.

The report points out that whilst legislation has been effective in driving down emissions of particles from the exhaust of internal combustion engine vehicles, the NEE proportion of road traffic emissions has increased.

The city’s emerging transport policies should now be more fully aligned with the strengthening of city’s air quality policies, by introducing Low Emission Zones (LEZ) and Automatic Number Plate Recognition (ANPR) systems.

Figure 42 – Elevated Tram track – Addis Ababa, Ethopia

3.5 Reduce congestion by building more roads?

An enduring counter argument which remains is that the way to deal with congestion is to build more roads and improve existing roads to increase the capacity of the road network. This despite the fact that for many years transport analysts have demonstrated that building more roads increases the number of journeys which eventually leads back to congestion - the construction of Dubai's orbital road network being the textbook example.

Best practice in the UK and European countries points to a public transport system which combines radial tram routes through the city centre to provide cross city routes (supported by feeder bus services) and upgraded BRT bus services on orbital routes.

The need for such a transformative modal shift from car travel to public transport in order to substantially reduce congestion and pollution, points to a mass transit system which combines tramlines and local rail services.

Given the 5–15 year timescale for constructing a tram network there is clearly a case for BRT to be deployed as an interim measure. In this scenario the two BRT routes identified in the City Centre Framework would be designated as Public Transport Pathways (PTP). They could use metro buses for their design life not to be succeeded by 'tram style buses', but to be converted to tram lines. It will be important to undertake 'before and after' impact studies of these BRT routes, to assess the extent to which they have attracted passengers who have switched from car use to buses.

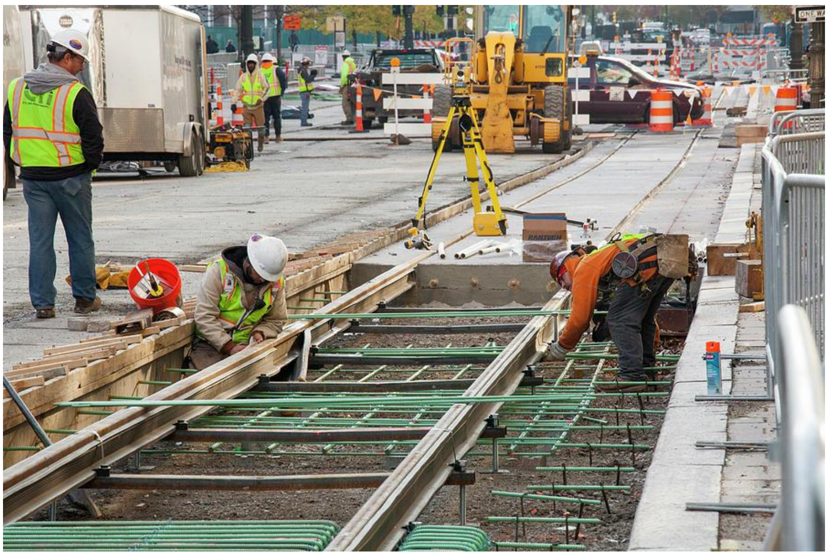


Figure 43 – Construction of rail track

3.6 The costs and benefits of tram-led and bus-led public transport

Operating costs

The cost of drivers dominates operating costs. One bus driver can serve up to 70 passengers whereas one tram driver can serve 200 plus. This means substantially lower operating costs per kilometre for trams compared with buses.

Moreover, trams are more energy-efficient than buses - a significant economic advantage. Like modern battery driven electric buses, they use renewable energy rather than fossil fuels. But all rail systems have the huge advantage of low energy use because of the very low rolling resistance of steel wheel on steel rail. This inherent energy efficiency advantage is enhanced by the fact that trams are the most easily electrifiable and efficient form of transport, using one electrical conductor on the rail with a simple overhead wire to complete the circuit, giving very high energy efficiency of around 90%.

A tram needs less power per kilometre than a bus, because it is lighter per axle and does not carry its own energy supply. Even if the option of on-board power is used, the energy efficiency of low rolling resistance remains in play. This may well be important in heritage building Conservation Areas where overhead wires may be considered unacceptably intrusive.

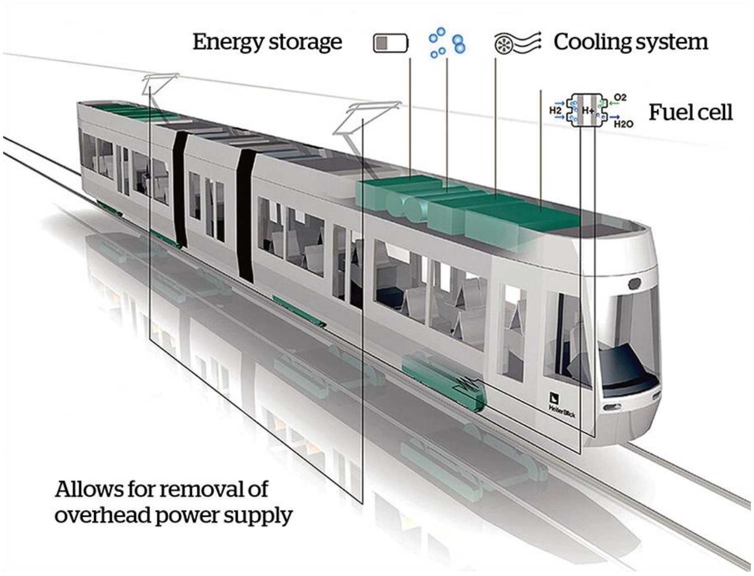


Figure 44 - Manufacturer HeiterBlick is developing a European-built fuel cell low-floor tram.

3.7 Capital costs – vehicles and track

But the capital costs of tram infrastructure are clearly much higher than for buses. A tram vehicle - depending on the choice of technology - costs about 5-8 times more than a bus. However, modern high-quality buses have an operational life of 12-15 years on the front line before being 'cascaded' to secondary uses, such as peak extras and country routes. In contrast, trams last over 30 years before being 'cascaded' to secondary uses - for example in Europe this process can extend the useful life of trams by a further 30 years (60 years in total).

Figure 45 – Low floor tram going through city

3.8 Fixed tram infrastructure and urban investment

There is significant and increasing evidence that the costly substantial fixed infrastructure brings important economic benefits which, to some extent, also offset the costs. This permanence is important for land use planning and stimulating commercial property investment along the route. Tram lines give both private and public sector investor confidence by providing long term certainty of predictable high levels of connectivity. In sharp contrast, bus services can be withdrawn at 90 days' notice. This physical infrastructure also provides a very visible and positive iconic image for the future of the city.

Figure 46 – Example of track installation process

3.9 Examples of “Ultra” or “Very Light Rail”

Operational in Morroco

Compact Example 1:

Citadis x02 trams 3 x 100 passenger vehicles operated by one ‘driver’ using semi-autonomous control

Manufacturer: Alstom
Based in California, operate internationally

Compact Example 2:
Trampower City Class

Capacity : 200

Manufacturer: Trampower Ltd
Based in Liverpool, UK

Operational in Lusail

Compact example 3:

Citadis X05 Vehicles
Low floor vehicles, 32 m length, 209 passengers.

Manufacturer: Alstom
Based in France

Operational in Blackpool

Compact example 4:

Bombardier Flexity 23 x 100 passenger vehicles operated by one ‘driver’ using semi-autonomous control

Manufacturer: Bombardier Transportation
Based in Germany, operate internationally

3.91 Easy installation of track without removal of utilities

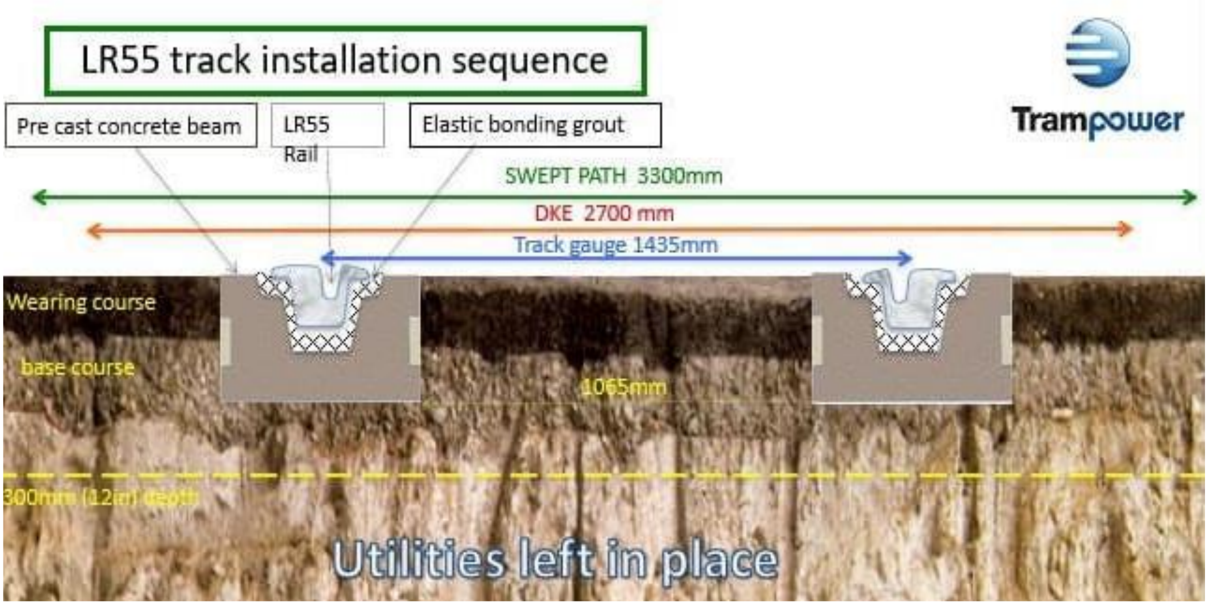


Figure 47 - LR55 "glue-in-road" tracks by Trampower Ltd

Wholesale road closure is not required and installation can be done outside peak hours.

The conventional wisdom of second-generation tram technology is that the installation of track requires the relocation of all utilities (gas and water mains etc.), typically adding at least 25% to the cost of the tramway. The contrast with third generation technology is illustrated using LR55 'glue-in' track technology. This technology does not require the closure of the road in which the track is being installed and does not require the re-location of all utilities. It can be installed at the rate of 100 m per week, without the need for complete closure of any roads and by keeping traffic moving by temporary management measures (see Fig. 46 above).

Moreover, autonomous guided trams may soon further drastically reduce operating costs. Already the TiG/m tram is operating a computer linked system in Doha which enables 1 driver to simultaneously operate three x 100 passenger trams.

3.92 Providing socially inclusive and active travel

From the point of view of overall tram network design, it is important that the phased development takes account of the need to serve lower income city neighbourhoods, as well as enabling long distance commuters to switch from their cars to trams.

3.93 Tram networks serve a diversity of passenger groups more flexibly than buses.

Similarly, the importance of 'hop-on' and 'hop-off' tram journeys on the main transport corridors should be considered in the calculation of passenger demand. At peak hours, the priority for shortening commuter journey times will require the operation of limited stop services. However, outside peak hours, stops could be more frequent.

Trams provide easier, level boarding access for people with disabilities or reduced mobility and multiple spaces for shopping bags, push chairs, wheelchairs and walking aids. They also provide spaces for cycles, albeit in limited numbers. For a diverse range of passengers, trams provide a welcomed smoother ride. All these qualities combine to generate much higher levels of passenger satisfaction than buses.

These factors are instrumental in persuading a range of both commuters and travellers using their cars for day-to-day shorter trips to leave their cars at home for many of their journeys. Non-Exhaust Emissions (NEE) to a system dominated by more energy efficient 'steel-on-steel' railways and tramways with no toxic emissions. This issue is not dealt with in the BRT Plan.

3.94 Light Rail Transit in Sub-Saharan Africa

There is a growing body of literature related to the contributions derived from and the diverse effects of LRT projects in developing cities. Other studies have focused on the societal and commercial consequences of urban rail and light rail transit (LRT) as their main subjects of investigation. Even in the face of biting economic hardships, several developing economies in Sub-Saharan Africa and South Asia have joined the trend and are earmarking railway infrastructure projects in their strategic development plans for the next 10 to 30 years . Railway infrastructure ventures are a paramount gesture and indicate one of man's greatest innovations towards the achievement of Sustainable Development Goals.

4. 0 A phased programme of indicative tram routes

The Plan applies the principles of an integrated tram-led strategy at route level to catalogue a comprehensive schedule of some 20 potential rapid transit routes, some of which have been briefed in the previous Transportation and Mobility Plan. The list includes more than a dozen proposed tram lines - most of them have been stipulated from studying the spatial flow of vehicles and trips discussed in the chapters above. The tram routes are connected to suburban, and densely populated urban lines including some important Tram Train proposals.

Moreover, the emphasis on the crucial importance of selecting the first line that is relatively straightforward to deliver, with the expectation that a successful first service will generate strong support for network extensions.

4.1 Rail transport services

Existing rail network cannot be easily used to operate urban transport services, considering that it is made by a single rail track with a high number of interferences with the road network and in bad maintenance conditions. Any change to the current rail network in the urban area may be expensive and would require a lot of time for planning and implementation. Also other high-capacity rail systems, such as a Metro, would require long time and high cost to be implemented.

However, considering that there are corridors characterized by high level of demand (e.g. between Omdurman and the City Centre), a high capacity and more reliable system like tram (partly or totally separated by road traffic) could provide transport services able to reduce congestion. Even if this transport mode is characterised by lower capacity in comparison with other rail systems, it has lower construction and operating costs. Furthermore, this system presents many advantages with respect to bus or mini-bus, such as:

- high travel speed, short and predictable travel times;
- punctuality and reliability;

- higher safety;
- Lower environmental impacts.

Thus, based on the above considerations, the more urgent and priority intervention appears to be the construction of a tram system. In the short term, the construction of a small tram network may be a realistic and achievable solution. However, this first system can be the basis for a forthcoming rail bound public transport system. The small network can be designed considering different hypotheses in terms of number of lines, length of lines, route layout, number of stops/stations.

Rail networks may represent an important resource for the urban transport. The current operating conditions and extension (i.e. a single rail track along the north – south axis) of the rail network in Khartoum do not allow the use of this transport mode for providing urban rail services in the short term. However, in the medium and long term, improvement of railway appears strategic for the mobility of Khartoum, and the implementation of the following actions will be pivotal to provide new rail services:

- Renewal of the rail network, in order to provide public transport services characterised by higher capacity and travel speed. The existing rail network will be particularly important for providing long distance rail services from Khartoum to other Sudanese cities and vice versa.
- Construction of new rail tracks on specific traffic corridors, such as a fast rail service between the City centre and the new Airport of Khartoum (that will be placed about 50 kilometres in the south of Khartoum). This rail line shall have at least one intermediate stop between the two origin/destination rail stations.

Table 4 – Short term - Medium term – Long term objectives of Tram / LRT System

Short term (less than 5 years)	Medium term (from 5 to 15 years	Long term (from 15 to 25 years)
Construction of a tram network with 2 lines: between Omdurman and Khartoum between Bahri and Khartoum	Construction of new rail tracks on specific traffic corridors, such as a fast rail service between the City centre and the new Airport of Khartoum	Converting rail infrastructure from regional to urban
Coordinated bus / mini-bus services in the exchanges nodes		
Exchange nodes • multimodal nodes in the central area • parking interchanges Coordinated bus / mini-bus services in the exchanges nodes	Exchange nodes • interline nodes • multimodal nodes in the peripheral area • with other transport nodes (e.g. the new airport) Coordinated bus / mini-bus services in the exchanges nodes	Exchange nodes (coherently with the tram/urban rail network development) • interline nodes • multimodal nodes in the peripheral area • with other transport nodes (e.g. the new airport) Coordinated bus / mini-bus services in the exchanges nodes
Develop a rail ticketing system	Develop a multimodal ticketing system	Develop a Multi rail ticketing system
Ancillary infrastructures: • traffic signal priority • road safety barriers protecting passengers	Ancillary infrastructures: • pedestrian crossing • level crossing	Ancillary infrastructures (coherently with the tram/urban rail network development): pedestrian crossing level crossing

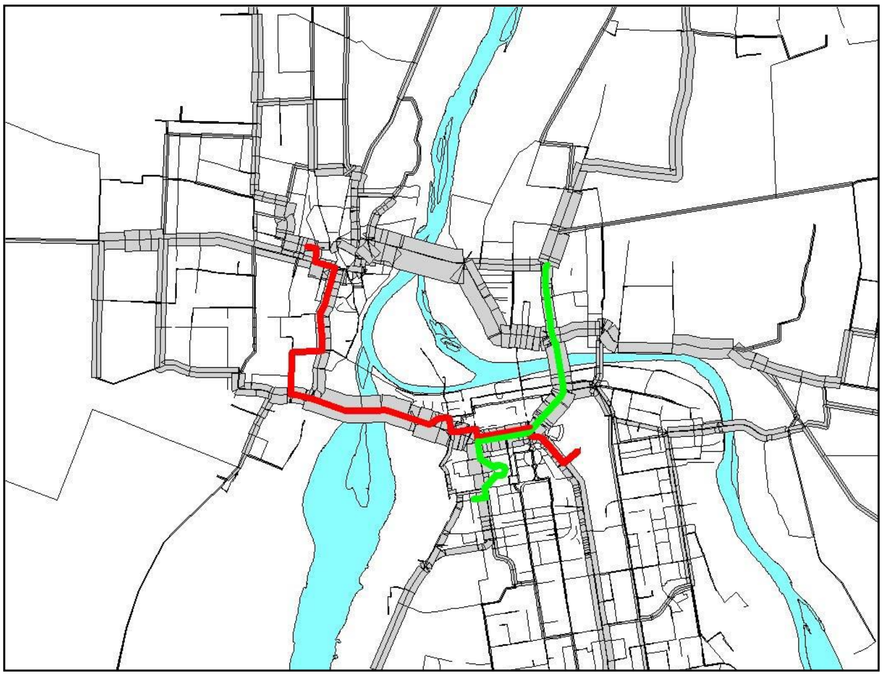
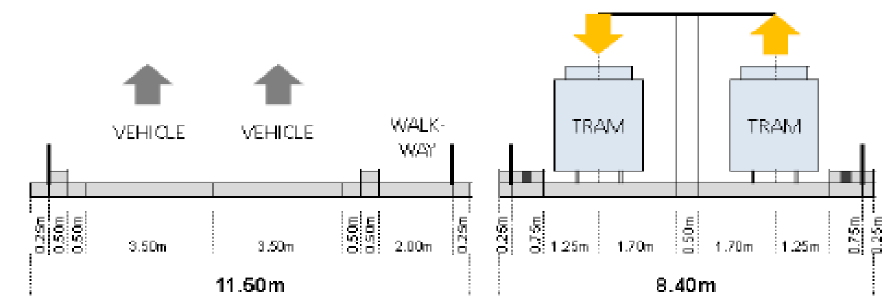
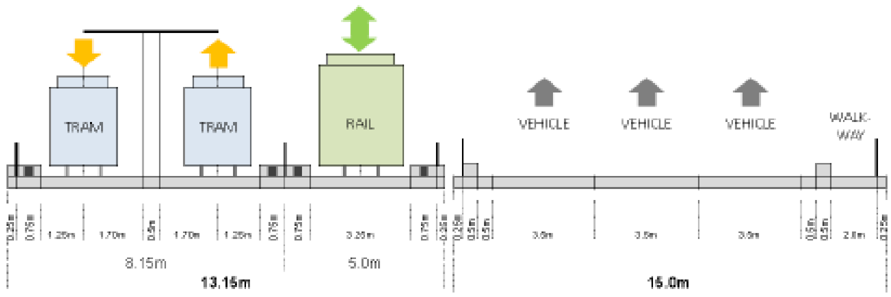


Figure 48 - Better tramway alternative, compared with public transport assignment

The short-term period the interventions to realize should be the construction of both tramway lines: that one that runs between Omdurman and Khartoum airport (see red line), passing into the center of Khartoum (crossing White Nile on Inqaz Bridge, without interfering with the two bridges with highest value of traffic flow) and that one between Bahri and Khartoum (see green line). This second line cut across the first line creating a point of interchange for passengers originated from different locations.

4.2 Bridge expansion for Tram Sections

جسر النيل الأبيض الجديد		**B5**
إنشاء جسر النيل الأبيض الجديد موازي وعلي بعد أقل من متر للجسر الحالي من الناحية الجنوبية وهو مكون من جزئين. الجزء الأول مكون من حارتين لمرور في اتجاه واحد للمركبات الخاصة من أمدرمان للخرطوم. والجزء الثاني مكون من جسر به مسارين لمركبات الترام. 		الوصف Description
20 m 2 للعربات, 2 للترام 600 m	ROW الحرم No of Lanes عدد الحارات Length الطول	السعة المرورية Traffic Capacity
$30 Million		التكلفة التقديرية Budget Cost
	Saving VKT Saving VHT Annual Benefits	الفوائد الاقتصادية السنوية Annual Benefits
		الفوائد / التكلفة B/C Ratio
Average Speed @ AM Peak = V/C Ratio = LOS =		معايير الكفاءة Performance Key Indices

جسر النيل الأزرق الجديد	**B6**
إنشاء جسر النيل الأزرق الجديد وهو مكون من جزئين. الجزء الأول مكون من 3 حارات لمرور في اتجاه واحد للمركبات الخاصة من الخرطوم الي بحري. والجزء الثاني هو جسر به مسارين لمركبات الترام ومسار لقطارات السكة حديد.  	الوصف Description
30 m | ROW الحرم 3 للعربات, 2 للترام, 1 للقطارات | No of Lanes عدد الحارات 560 m | Length الطول	السعة المرورية Traffic Capacity
$41 Million	التكلفة التقديرية Budget Cost
Saving VKT Saving VHT Annual Benefits	الفوائد الاقتصادية السنوية Annual Benefits
	الفوائد / التكلفة B/C Ratio
Average Speed @ AM Peak = V/C Ratio = LOS =	معايير الكفاءة Performance Key Indices

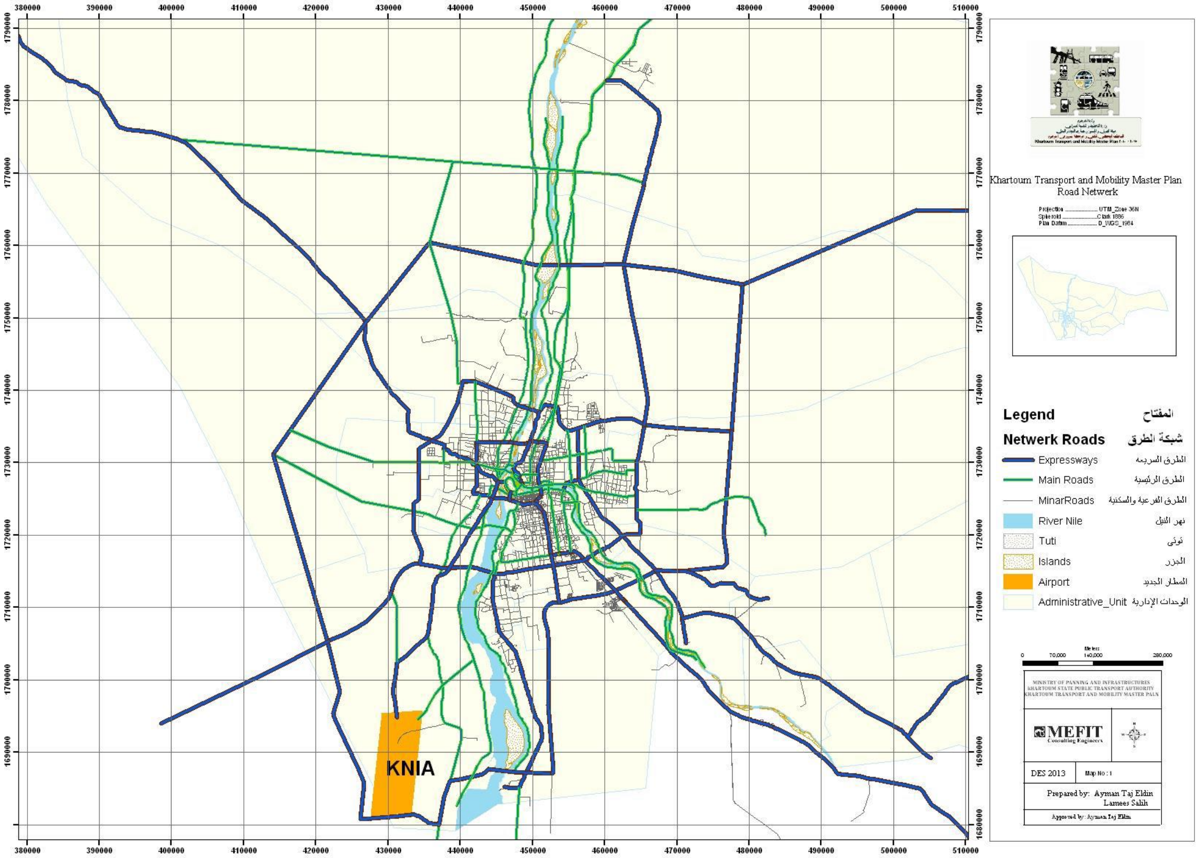


Figure 49 – Major Road Network in Khartoum

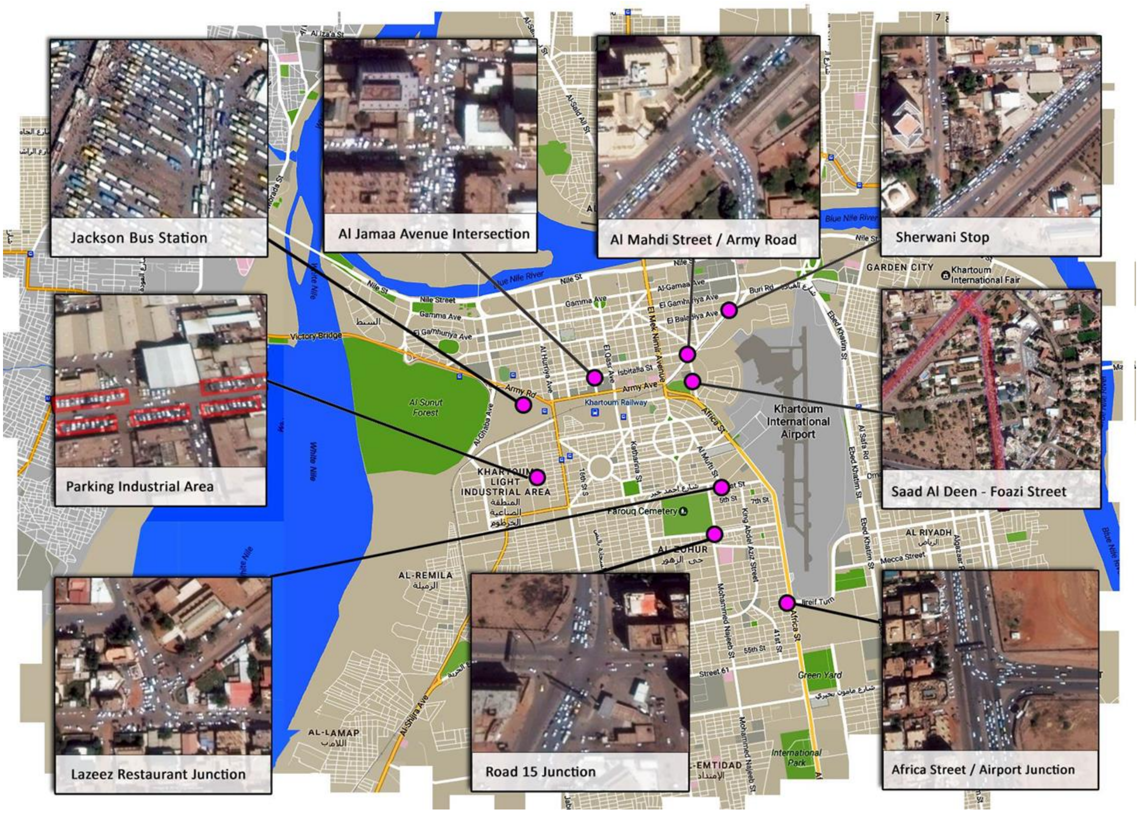


Figure 50 – Khartoum Major road junctions

تقدير عدد القطارات المطلوبة

LRT Routes

Fleet # عدد المركبات	Capacity سعة المركبة	Headway @ Peak Hr التقاطر في ساعة الذروة	Length الطول	Description الوصف	Route # رقم المسار
	Pass	Min	Km		
8	250	10	11	أمدرمان (استاد الهلال) - الخرطوم (الجامع الكبير)	LRT11
8			11		
11	250	10	15	أمدرمان (استاد الهلال) - المطار	LRT12
15	250	7	15	بحري (السوق المركزي) - محطة السكة حديد (كركر)	LRT21
9	250	7	9	سوق ليبيا - استاد الهلال	LRT31
34	500	9	21.5	سوق ليبيا - محطة السكة حديد (كركر)	LRT32
17	250	7	17	سوق ليبيا - بحري (محطة السكة حديد)	LRT33
15	250	7	15	الحاج يوسف - بحري (المحطة الوسطى)	LRT41
19	250	7	18	الحاج يوسف - محطة السكة حديد (كركر)	LRT42
13	250	13	23	الحاج يوسف - أمدرمان (استاد الهلال)	LRT43
133			133.5		
15	250	8	17	الشنقيطي - استاد الهلال	LRT61
32	500	10	28	الشنقيطي - الخرطوم (الجامع الكبير)	LRT62
46	500	8	25.5	خور عمر - الخرطوم (الجامع الكبير)	LRT71
30	500	8	17	الخرطوم (الجامع الكبير) - عد حسين	LRT81
13	250	8	14.5	الخرطوم (الجامع الكبير) - المعمورة	LRT82
19	500	9	21	كبري الحلفايا - محطة السكة حديد (كركر)	LRT22
18	250	8	20.5	الخرطوم (الجامع الكبير) - الثورة بالنص	LRT72
173			143.5		
314					

تقدير الطاقة الكهربائية المطلوبة

- يعتمد تقدير الطاقة الكهربائية علي عدة عوامل أهمها:
  - أقل تقاطر بين القطارات
  - القطاع الذي تمر به أكبر عدد من القطارات
  - التسارع المطلوب لتحريك القطارات عند المحطات
  - عدد المحطات
  - عدد تقاطعات الاشارات الضوئية التي تحتاج الي وقوف ثم تحرك
- الطاقة المطلوبة لشبكة بطول 130 كم حوالي MVA <u>**160**</u> (حوالي 140~ 120 ميغاوات)
- انشاء خزان السبلوقة وتخصيص الكهرباء المتولدة لمشروع الترام (حوالي 120ميغاوات)

4.3 Light Rail vs Heavy Rail

Table 5 – A comparison of basic characteristics of Light and heavy rail[1]

Characteristics	Light Rail	Heavy Rail
Population	100,000 - 1 million	>500,000
Type of Line	Mainly Separated from road traffic on street level	Completely separated from road traffic
Medium distance between stops (m)	250 - 1200	1000-5000
Engineering	Light	Medium to heavy
Maximal gradients (%)	08-Oct	3
Minimal Radius (M)	15-25	200
Carriage weight (t)	<20	40-50
Maximal frequency (trains/hr)	40-60	24-40
Transport capacity (Passengers/hr)	8000-15,000	30,000-60,000
Average Speed (km/hr)	10-40	40 - 80

Table 6 – Light Rail Projects in Africa

Urban Railway Transit in Africa		
Suburban rail	Operation	Nairobi rail service, Botswana Railways (BR Express), Dar el salaam commuter rail, Metrorail western cape, Metrorail eastern cape, Metrorail Gauteng, Metrorail KwaZulu-Natal, Al Bidaoui, Gautrain, Petit train de banlieue
	Under construction	Train express regional
Rapid transit	Operation	Algiers metro, Cairo metro
	Under construction	Abidjan metro, Lagos rail mass transit
Light rail	Operation	Addis Ababa light rail, Abuja light rail, Métro léger de Tunis, Sidi bel Abbés tramway, Trams in Alexandria, Casablanca tramway, Oran tramway, Algiers tramway, Constantine tramway, Ouargla tramway, Sétif tramway, Rabat-salé tramway
	Proposed	Nairobi light rail, Greater Kampala light rail

5.0 Schematic Diagram of Proposed Tram Network

The development and application of the assessment method for this limited study took place under Covid restrictions which prevented on-site visits. This meant inevitably time-consuming reliance on Google Earth and route-planning software

Tram stops are spaced every 400m (approx.) - within cycling and walking distance of substantial residential catchment areas with easy access to major retail and employment locations, health, and educational facilities, both existing and planned, and the local rail network.

Tram stops are co-located with bus feeder-stops, ‘bike+ride’ and ‘scoot+ride’ facilities to provide ‘community transport hubs’ which attract tram passengers and encourage active travel within adjacent 15–20-minute liveable neighbourhoods.

Figure 51 - Three Proposed Tram routes across Khartoum, Bahri and Omdorman

The purpose of this pre-feasibility study is to test the suitability of the proposed Phase 1 routes for full feasibility studies. The outcome of the application of the pre-feasibility method is set out in Section 5 which indicates that there are no engineering, re-allocation of road space, or traffic management issues which would preclude the provision of an on-street tramway along each of the three routes - there are no apparent showstoppers. However, in some locations space will be tight.

Figure 52 - Three Proposed Tram lines

Figure 53 - Proposed Routes Lengths and Estimate Costs

All three tramlines would be street running, sharing with other vehicles as appropriate, but with traffic management priority for trams.

Thus, this proposed network builds on the Transportation and Mobility Study which rightly emphasizes the crucial importance of phasing the transformation of Khartoum's public transport system, in the context of integrating the proposed Khartoum Tram Network with current bus routes.

The progressive delivery of the three primary network routes by 2031 would demonstrate the case for further implementation of extension of Phases 2 and 3 in the period 2031-2040.

5.1 Kickstarting the First Tramline within 5 years

Stage 1: from Pre-feasibility Study (to identify starter routes), through Feasibility Study (routes evaluation and selection of preferred routes) to ***First Stage Consultation*** (on the principles of the proposed network), and Local Authority funding ***application*** to Department of Transport.

Minimum 12 months

Stage 2: begins with funding approval, subject to meeting all subsequent statutory processes, which focus on a second stage consultation followed by an application for ***Traffic & Works Act Order*** (TWAO) which is subject to a Public Inquiry.

Minimum 18 months

Stage 3: approval following a public inquiry releases government funding which enables the Local Transport Authority to specify and commission the ***detailed design*** of the tramways and depots.

Minimum 12 months

Stage 4: **implementation** construction of the tramway, procurement of vehicles and development of operational capacity.

Minimum 24 months

Total minimum time is 5 years, 6 months from Pre-feasibility Study to Starter Line in operation

Table 6 – Stages of consultations and development of design

In this context it is reasonable for Khartoum Transport to campaign for a Greater Khartoum Tram Network to be developed in three phases:

Phase 1 Starter Line operational by 2026-27

Phase 2 Primary Tram Network completed by 2031

Phase 3 Khartoum Regional Tram Network substantially completed 2031 -2040

5.2 Components of the pre-feasibility assessment method of 3 potential lines

The assessment method includes three basic components: (1) potential passenger demand, (2) re-allocation of road space and (3) the location and multiple purposes of tram stops.

Road sharing

For most of their length the Primary Network routes run through built-up areas. Therefore, this assessment assumes the tramlines will generally be road sharing i.e. continually used by other vehicles – buses, cars, and cycles. This will be subject to dedicated Right of Way (ROW) priority being given to trams by a combination of traffic management arrangements and minimum use of segregated lanes.

Trams and Pedestrians in Amsterdam shopping street

Approach to the tram stop well signed and alerting drivers by its visual presence.

Passengers and cyclists cross the three-lane Rd protected by Zebra crossing and where required

An example where the road narrows and is shared with pedestrians, bicycles bus and taxi only

Bus & Tram Public Transport Pathway (PTP)

An example of a strictly controlled delivery bay for LGVs below 18 tonnes

However, in considering the total time to complete journeys (TTTC) city speed limits will be applied to tramlines. Nonetheless, the TTTC for trams will on average be quicker than buses, and trams will generate zero pollution, in sharp contrast to the NEE pollution of buses.

Finally, in line with normal tram network practice LGVs over 18 tonnes will be prohibited along the tram line routes.

Addis Ababa Light Rail / Tram

Casablanca – Morrocco tram passing city at road level

5.3 Road sharing - tramlines and cyclists

It must be fully acknowledged that cyclists and pedestrians may focus on the perceived hazards more than the promise of improved cycling conditions on far less congested roads. However, as these images demonstrate, a combination of physical measures, signage and a willingness to embrace adjustments to new cycling conditions can ensure safety and reap the benefits of the major reduction in motorised traffic, whilst providing convenient access to trams for longer journeys.

Scooters, bikes and trams can - with care - share road space

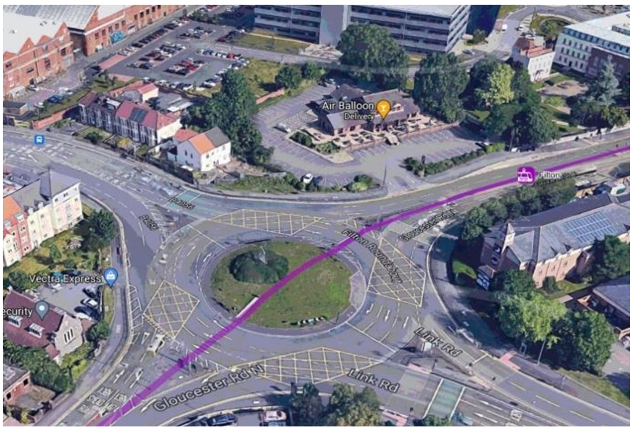
Crossings not less than 45° should be engineered in at time of construction to ensure cycle safety

A busy Bike + Ride stop serving both directions

“Red Paths” for safe cyclists” to cross tram tracks at a safe angle

5.4 Road Junctions

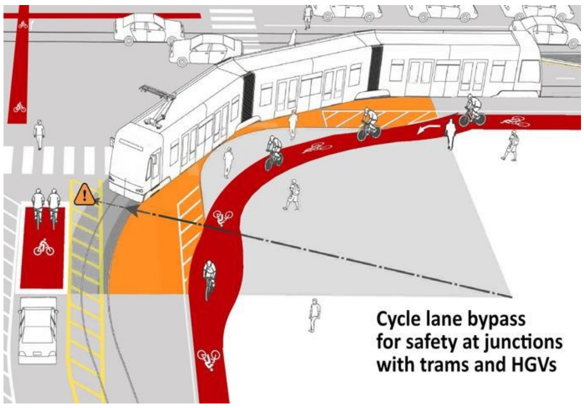
Junctions between the proposed tram lines and other roads, particularly roundabouts, can also be assessed to ensure the practicality of the dedicated right of way (ROW) needed for efficient tram operations.



An example of how the tram could pass through the centre of roundabout

5.5 Depots - number, site requirements and potential locations

Identifying sites for the location of depots for tram rolling stock storage and maintenance is often the most contentious issue which will have to be resolved in the feasibility study. The first depot must be adjacent to the first line, with space on the site for expansion. The choice of sites will be determined in the full Feasibility Studies. However, at this stage it appears that it may well be necessary to have a minimum of two depots to service the suggested Primary Tram Network and eliminate dead mileage - one north of the city center and one to the south



Large Tram depot

Tram network management to deliver equal access for a diversity of passengers to affordable and reliable public transport.

5.6 Traffic management and parking in shopping areas

There will inevitably be a reduction in the availability of on-street parking, but this will be in the context of the tram providing an attractive alternative to using cars to access local facilities.

The management of deliveries to retail and commercial premises will have to be carefully planned, drawing on experience of new ideas, such as supplementing delivery bays with ‘cargo tram’ options, where at certain times of day trams replace delivery vehicles.

Improving the Streetscape

6.0 Conclusions & Recommendations

The overall conclusion is that the proposed Khartoum Primary Tram Network, with its phased development of three core tram lines, should be subject to a full feasibility study and preliminary design, which would compare it to other network options for the development of a mass rapid transit system for Khartoum.

This limited project first developed an ‘in principle’ case for a ‘tram plus local train’ rapid transit system for Khartoum over 10-15 years, with a first line operational within 5-7 years.

This outline tram-based rapid transit proposal will support the engagement in the range of public consultations on transport and spatial planning policies which are scheduled to start in summer 2022 and be followed by formal public examinations in 2022.

Figure 54 – Based on number of trips

Keep It Straight Consultants with its partners will be consulting on the outcome options for mass transit, assessing routes that will have the highest volume of passengers and connecting with existing and planned bus services. In parallel will be consulting on the Joint Spatial Development Strategy which will confirm the location of planned housing and employment for the next 15 years.

A city centre loop would be necessary to maximise cross-city connectivity and that second phase Local Tramway Loops would provide high quality public transport services for hospitals, shopping and recreational/leisure facilities, together with a diversity of inner city and suburban neighbourhoods.

6.1 Choice of Starter Line

The choice of starter line will require a comparative assessment of the financial benefits and costs of the three lines, in the context of an assessment of their social and environmental cost and benefits. This assessment should also evaluate the option of developing Lines 1 and 2 simultaneously

6.2 Khartoum – a third generation city

Khartoum now has the opportunity to be the first Sudanese city to both embrace the emerging third generation tram technology and the relatively new pollution science of non-exhaust emissions. Such a transformational tram-led public transport system will effectively address the legacy of congestion and pollution by delivering a much higher level of modal shift from private cars to public transport than is possible with Bus Rapid Transit- led system.

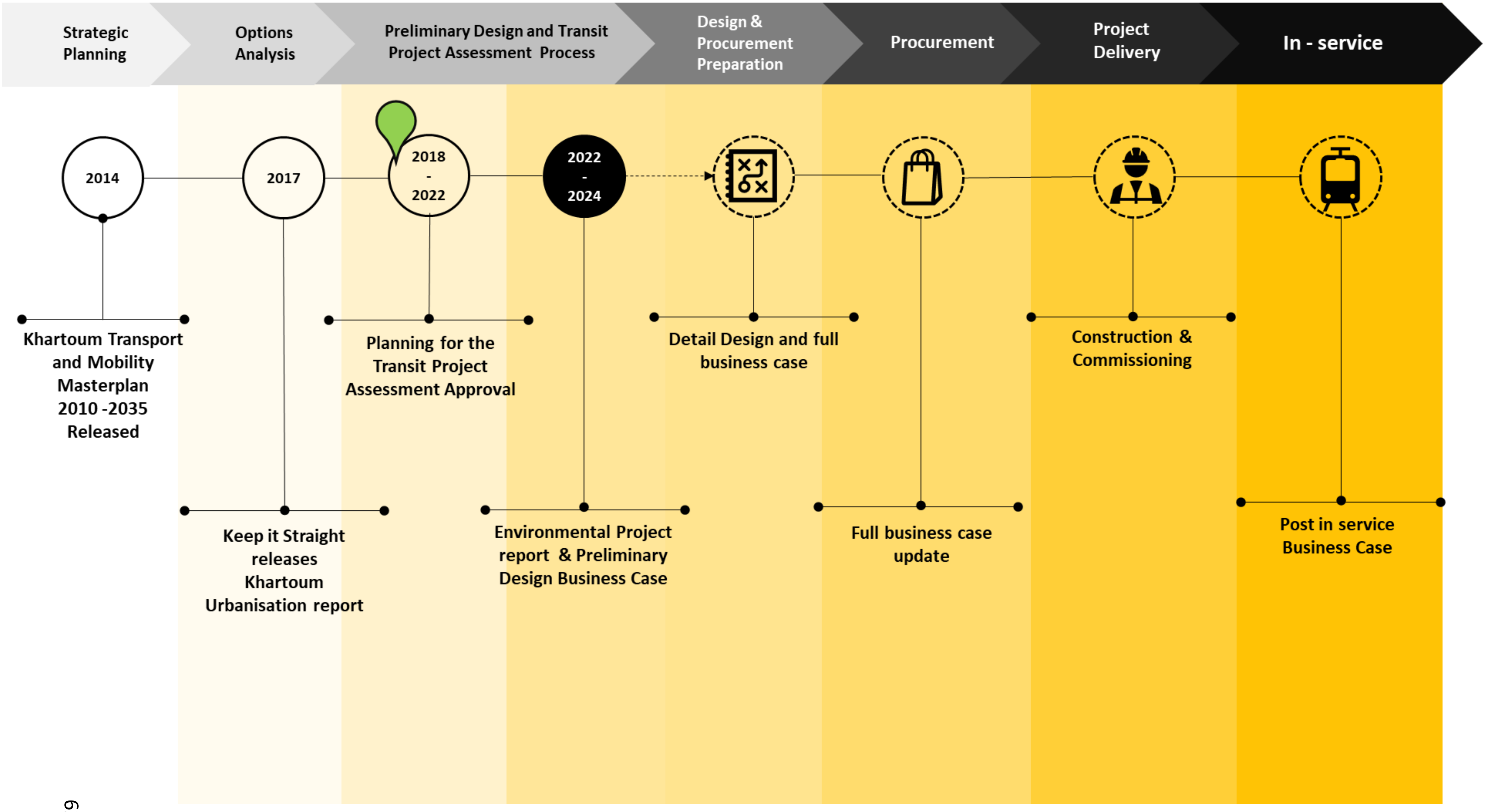
Moreover, in taking this opportunity Khartoum could also be the first major city to take fully and explicitly into account the new and emerging science, which establishes the threat of pollution from non-exhaust emissions as a key driver of a 'steel on steel' tram and local rail public transport system.

6.3 Continuing community engagement – 'build back better by bringing back trams'

There is an opportunity for Khartoum Infrastructure and Transportation Authorities to draw on technical advocacy to develop a 'hearts and minds' campaign to win public support for the phased development of a Khartoum tram network.
Joint work to maximize public and community engagement first stage public consultation on options for developing rapid transit system which is scheduled for this summer;

- distilling and promoting the 'steel on steel' cost effectiveness and proven modal shift arguments which underpin the case for re-introducing trams;
- securing funding to enable community representatives to visit cities which have established tram networks that are currently being extended; and
- developing a pilot neighborhood case study visioning project which would explore the potential of a tram based public transport system to support the further development of cycle

6.4 Workflow Schedule



6.5 Business Case Work Stream

1 Strategic Planning

Identifies problem statement and defines benefits that the project needs to deliver.

2 Feasibility and Options Analysis

Evaluates options and determines a preferred option. Typical point at which funding for planning and preliminary design is secured.

Initial Business Case

- The Initial Business Case compares investment options and selects a preferred option for further refinement and design.
- This Business Case is typically used to secure funding from the Province for planning and preliminary design.

3 Preliminary Design

Refines preferred option, further clarifying scope and cost. Typical point at which funding for procurement and construction is secured.

Preliminary Design Business Case

- The Preliminary Design Business Case takes the recommended option of the Initial Business Case and reviews different approaches to refine and optimize it.
- This Business Case is typically used to secure funding from the Province for procurement and construction.
- This stage of the Business Case Lifecycle typically occurs in parallel with the Environmental Assessment process.

4 Design & Procurement Preparation

Develops project framework, designs and requirements used as the basis for procurement.

Full Business Case

- Full Business Case confirms a specific option (including benefits realization, financing, and delivery plans) for procurement.

5 Procurement

Procures the project.

Full Business Case

- Updated (if required).

6 Construction, Commissioning & Delivery

Delivers and commissions the project.

Post In-Service Business Case

- The Post In-Service Business Case reviews the actual costs and performance of the investment after the asset has gone into service. This Business Case provides lessons learned and opportunities to enhance the services being provided.

7 In Service

After the asset is in service, monitors the benefits and costs to identify opportunities for enhancements and lessons learned.

Preliminary Design and Feasibility study will require international collaboration to create the best service for all issues related to topography, track design, systems, signalling, safety and rolling stock.

Figure 56 – Conference on Development of clean transport

Figure 57 – Expo on latest rolling stock developments

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Light Rail Tram for Khartoum, Sudan

Prefeasibility Report

Building on the Transport for Khartoum Transportation Plan to propose a Primary Tram Network Phased over 10-15 years

Prepared by KISCO Ltd

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