Nairobi Ndovu/A104 BRT Service Plan

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List of Abbreviations

Artic: Articulated buses (18 meter)

BA: Boarding and Alighting

BRT: Bus Rapid Transit

CBD: Central Business District

FVO: Frequency and Visual Occupancy

ITDP: Institute for Transportation & Development Policy

JKIA: Jomo Kenyatta International Airport

KeNHA: Kenya National Highways Authority

LRT: Light Rail Transit

MRTS: Mass Rapid Transit System

MIT: Massachusetts Institute of Technology

NMR: Nairobi Metropolitan Region

NUTRIP: National Urban Transport Improvement Project

OD: Origin-Destination

Std: Standard buses (12 meter)

0 Executive Summary

The Institute for Transportation and Development Policy (ITDP) is a non-profit organization with extensive technical expertise on Bus Rapid Transit (BRT) planning. One of our core missions is to help cities to improve the quality of their BRT projects. As such, we have worked in cities around the world to help design and implement some of the best ranking, gold-standard BRT systems.

The Ndovu/A104 BRT project in Nairobi is currently on a trajectory to become a world-class BRT project. The highest quality BRT systems are designed around a good service plan. A service plan determines where the BRT routes will go, how big stations will need to be, and how many passengers a BRT system will attract. The BRT infrastructure is then designed specifically for this service plan.

At the request of the Kenya National Highways Authority (KeNHA), ITDP has prepared a preliminary BRT service plan for the Ndovu/A104 BRT project according to international best practice in BRT service planning. This report details the process, methodology, and modeling results from several detailed alternative service scenarios. The recommended service scenario in this report minimizes land acquisition, reduces the capital costs needed for transfer stations, minimizes travel time for passengers, and attracts the most passengers. The results of each alternative option are shown. The best scenario for the project would result in a top-quality BRT that can be replicated in Nairobi, in Kenya, in East Africa, and throughout the world.

0.1 Scenarios Compared

Comparison of Five Service Plan Scenarios						
Scenario	Baseline	I	II	III	IV	V
Description	Existing	I: Trunk & Feeder, no CBD	II: Direct Services, no CBD	III: Trunk & Feeder, CBD	IV: Direct Services, CBD	V: Direct Services, CBD + Langata
Trips on Matatus	966,213	732,213	606,213	669,213	597,213	516,213
Daily trips	0	234,000	360,000	297,000	369,000	450,000
Time per passenger	78.36	77.21	76.40	75.4	74.10	72.03
Time savings all passengers	0	1.15	1.96	2.96	4.26	6.33
Time savings per BRT passenger	0	5.1	5.7	10.5	12.1	14.7
BRT Vehicles	0	284	352	343	335	385
Daily passengers per bus	0	824	1023	866	1101	1169
Transfer stations needed	0	6	0	6	0	0

Table 1: Comparison of the 5 service plan scenarios

Six scenarios were modeled and compared. These six scenarios are as follows:

- **Baseline**: Existing conditions
- **Scenario I**: Trunk-feeder services with trunk services on A104 only
- **Scenario II**: Direct services with BRT infrastructure on A104 only

- **Scenario III**: Trunk-feeder services with trunk services on A104 and through the CBD (BRT infrastructure through CBD too)
- **Scenario IV**: Direct services with BRT infrastructure on A104 and through the CBD
- **Scenario V**: Direct services with BRT infrastructure on A104, through the CBD + 1.5km of Langata Rd.

Each scenario was compared on the following terms:

- Daily ridership on the BRT;
- Average time savings all transit passengers (BRT + matatu);
- Average time savings, BRT passengers;
- # BRT vehicles needed;
- Daily passengers on each bus; and
- # Transfer stations needed.

The best BRT service plan will capture as much of the existing matatu demand currently using the corridor as possible. This has two benefits: First, it means more of the matatus can be removed from the remaining traffic lanes, decongesting the road. Second, it means more passengers can benefit from the new BRT system. Scenario V captures by far the most passengers, and hence would decongest the road the most.

The best BRT service plan will save the most time for all the transit passengers in the corridor, both those on the BRT system and those that cannot use the BRT system. It is also worth knowing how much time just the BRT passengers save. In this respect, Scenario V also performs the best. All transit passengers save 6.33 minutes and the BRT passengers save 14.7 minutes per trip under Scenario V. Scenario V performs the best because the infrastructure is concentrated on the most congested parts of existing transit trips, and because there are minimal forced transfers imposed on passengers.

The best BRT service plan carries the most passengers per bus but does not necessary require the smallest fleet. The best BRT service plan requires a bigger fleet because it is carrying a lot more passengers than alternative scenarios, but each one of those buses is carrying more daily passengers than in the other scenarios, so the system overall will be more profitable.

The best BRT service plan requires lower capital costs and land acquisition.

Summary of Estimated Capital Costs by Service Plan Scenario						
Scenario	Baseline	I	II	III	IV	V
Description	Existing	Trunk & Feeder, no CBD	Direct Services, no CBD	Trunk & Feeder, CBD	Direct Services, CBD	Direct Services, CBD + Langata
Total Estimated Capital Cost	0	$ 262,950,000	$ 208,200,000	$ 296,150,000	$ 210,300,000	$ 239,650,000

Table 2: Summary of Estimated Capital Costs by Service Plan Scenario

The capital costs for the trunk-and-feeder scenarios (I & III) are much higher largely because of the need to acquire land and construct six transfer stations. This adds an estimated $106.8 million to the cost of all trunk

and feeder scenarios (though some of this is offset by smaller fleet sizes due to a much lower ridership). In the scenarios with infrastructure in the CBD, that infrastructure adds only $2.7 million in busway costs and about $6.5 million in station costs, so about $9.2 million total. Extensive land acquisition in the CBD is unlikely to be necessary under the direct services scenarios, as the right-of-way is already quite wide. For this initial investment, about $70 million more is achieved in user benefits in the trunk-feeder scenario, and more than $110 million a year in additional benefits in the direct service scenario. The capital cost in the direct service scenarios with CBD (Scenarios IV & V) for buses drops because it runs services in highly congested downtown streets, and increasing these speeds significantly reduces the amount of fleet needed.

Summary of Rate of Return by Service Plan Scenario							
Scenario	Baseline	I	II	III	IV	V
Description	Existing	Trunk & Feeder, no CBD	Direct Services, no CBD	Trunk & Feeder, CBD	Direct Services, CBD	Direct Services, CBD + Langata
Estimated annual benefit (USD)		$ 5,592,894	$ 9,123,762	$ 13,422,946	$ 21,897,029	$ 25,286,662
PV 12 Years @ 5%		$ 49,571,230	$ 80,866,199	$ 118,970,952	$ 194,078,877	$ 224,122,047
Total Estimated Capital Cost	0	$ 262,950,000	$ 208,200,000	$ 296,150,000	$ 210,300,000	$ 239,650,000
Rate of Return		0.188519605	0.388406334	0.401725316	0.922866748	0.935205703

Table 3: Summary of rate of return by service plan scenario

In terms of rate of return, the CBD section has the highest rate of return of any capital investment in the corridor. Finally, the rate of return is far better for the direct service scenarios, and for all of the scenarios including the CBD infrastructure, and somewhat better still if Langata is included. This, once again, points to Scenario V as being the best investment.

0.2 Recommended Service Scenario: Scenario V

The best-performing scenario was Scenario V: "Direct services on KeNHA Infrastructure + CBD + Langata." In this scenario, multiple services, which mimic the most popular existing matatu routes, operate in mixed traffic for a part of their route, then enter full BRT infrastructure along the A104. This scenario also requires full BRT infrastructure on the first 1.5km of Langata Rd and in the city center. This service option captures most of the existing passengers using the corridor today and offers them a convenient "one-seat ride." Of the dozens of existing matatu routes, we simplified them and reduced them to 16 critical routes which include some local and express versions of the same routes. The resulting service plan is depicted below, with details included in Chapter 5.
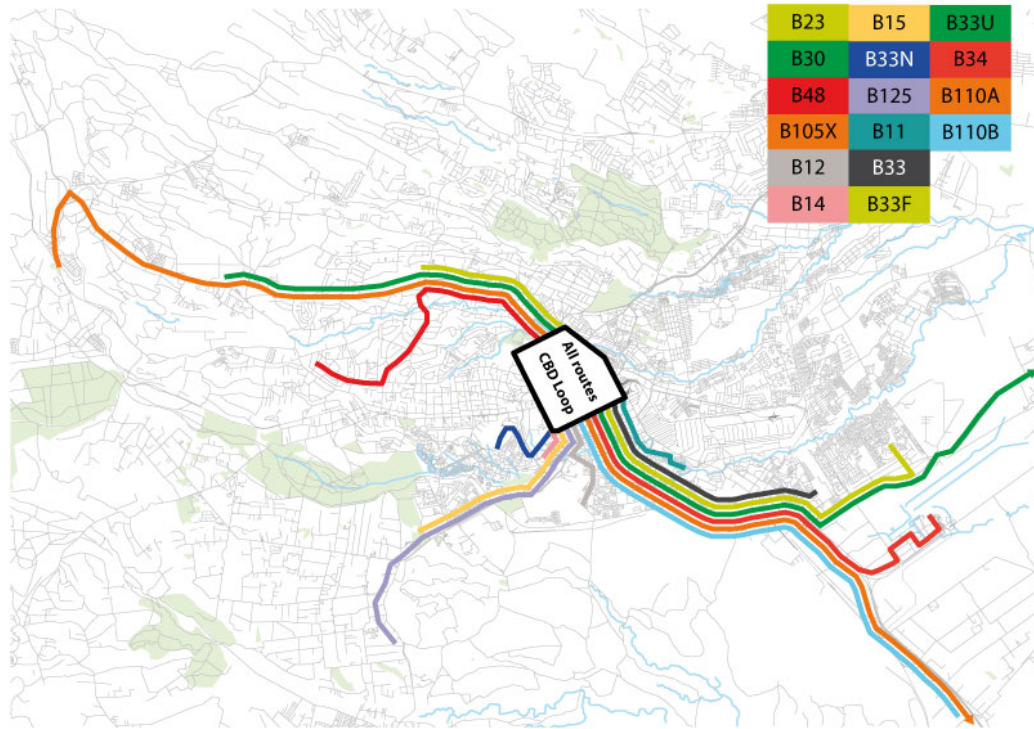
Figure 1: BRT service scenario V: Direct services on KeNHA Infrastructure + CBD + Langata

The total number of AM peak hour passengers who will use the BRT in this scenario is 49,887, which will attract approximately 450,000 daily passengers, making it the highest-performing scenario. This will require a total fleet of 385 buses: 266 articulated 18 meter buses and 119 standard 12 meter buses. To ensure optimal operational flexibility, the 18 meter buses should be specified to have four platform-level doors on the right side of the bus, and two curb-level doors on the left side. The 12 meter buses should have two platform-level doors on the right side and two curb-level doors on the left. If a low floor design is opted for, both sets of doors can be at the same level.

Currently the average trip consumes 78.36 minute equivalents, and the recommended scenario reduces this to 72.03 minutes, a reduction of 6.33 minutes for all transit passengers using the corridor and **a reduction of 14.7 minutes per peak hour BRT passenger on average**. When this figure is combined with the estimated cost of building the system, a preliminary economic rate of return can be calculated, which will be needed to justify the investment to the World Bank.

We are also confident that this service plan will attract sufficient customers willing to pay a reasonable fare that a private investor will be able to recover their needed investment in buses from the farebox as well as their ongoing operating costs and still return a profit.

This result depends critically on the completion of full BRT infrastructure on University Way, Haile Selassie Ave, and Moi in the Nairobi CBD. Additionally, as four of the higher-volume routes come from Langata Rd, this

result also depends on full BRT infrastructure for the first 1.5 km of Langata Rd, designed as part of Phase I. Further, the fully dedicated BRT-only turns that were recommended in the "Nairobi BRT Phase I Infrastructure & Intersections" report (Riverside Dr, University Way, Haile Selassie Ave, Langata Rd, Popo Rd, Enterprise Rd, and Airport N Rd) remain critical to accommodating these services and ensuring that the BRT speeds do not drop sharply due to lack of intersection capacity. If these elements of BRT infrastructure are excluded from Phase I, a majority of the benefits of the project are lost.

The detailed results of the modeling (shown for the AM peak hour) are below. Note that "Artic" indicates an 18 meter articulated bus, and "Std" indicates a 12 meter bus. Both must be configured for use on- and off-corridor.

DATA MODEL			MODEL RESULTS								
Route	Veh type	Length (km)	Run time (min)	Boarding	Pax km	Pax hours	Max volume	Max load	Freq	Hdwy (min)	Fleet
B105X	Artic	44.9	162.34	7 599	101 573	6 276	3 846	1.20	24.0	2.5	66
B11	Std	15.5	67.08	1 996	6 732	576	1 024	0.57	11.4	5.3	13
B110A	Std	62.4	168.21	2 338	37 183	1 427	973	0.54	10.8	5.5	31
B110B	Std	41.7	108.12	1 575	18 440	713	906	0.50	10.1	6.0	19
B12	Std	16.5	80.61	1 136	4 255	241	592	0.33	6.6	9.1	9
B125	Artic	28.5	154.39	3 284	22 645	2 395	1 789	0.56	11.2	5.4	29
B14	Std	10.5	35.70	1 152	3 501	210	909	0.51	10.1	5.9	7
B15	Artic	25.1	137.44	3 615	17 833	1 675	1 211	0.38	7.6	7.9	18
B23	Artic	22.0	62.36	5 672	37 227	1 859	2 980	0.93	18.6	3.2	20
B30	Artic	29.6	89.16	6 142	39 934	1 960	2 707	0.85	16.9	3.5	26
B33	Artic	24.0	56.42	5 336	44 092	1 801	2 888	0.90	18.1	3.3	17
B33F	Artic	35.4	139.64	3 148	29 658	1 505	1 343	0.42	8.4	7.1	20
B33N	Artic	15.9	56.90	2 378	13 086	866	2 063	0.64	12.9	4.7	13
B33U	Std	50.3	232.00	3 620	20 678	1 569	929	0.52	10.3	5.8	40
B34	Artic	38.4	108.79	3 480	38 189	1 579	1 643	0.51	10.3	5.8	19
B48	Artic	28.1	140.04	4 071	35 198	2 768	2 540	0.79	15.9	3.8	38
TOTAL		489	1799	56 542	470 225	27 420					385

Table 4: Results of Scenario V

Our modeling also produced station by station passenger boarding and alighting volumes, from which we are able to provide station sizing recommendations in terms of number of sub-stops. A sub-stop is a station module with enough space for two buses to dock. Sub-stops should be separated by enough space for a bus to easily pull in and pull out if there is another bus in front of it.

Figure 2: BRT station in Johannesburg with two substops

The map below shows how many sub-stops are needed at each station in order to accommodate the passenger demand without saturating. The need for the greatest number of substops in the CBD underscores the demand and need for BRT infrastructure in the CBD from the start of operations.
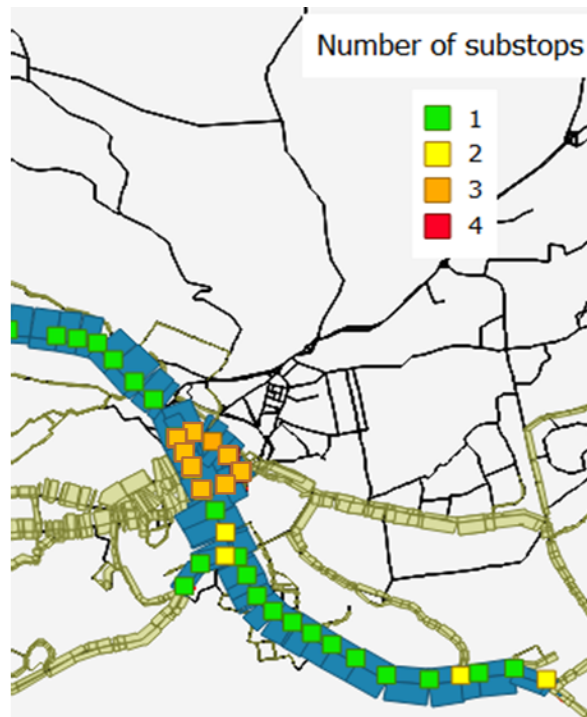
Figure 3: Number of sub-stops needed at each station under recommended service plan scenario

One of the main reasons ITDP recommended a full BRT ring through the Nairobi CBD was to increase the number of stations able to handle CBD-bound passengers. By having 9 full BRT stations in a full ring around the Nairobi CBD, the CBD-bound demand on the A104 can be distributed throughout the CBD. This not only avoids

any one station becoming overcrowded and saturated, it also minimizes walking times. The alternative proposal, to have only 4 stations along the A104 would result in all of the demand concentrated in only 4 stations, and not only would these stations saturate, they would also be far from trip origins and destinations, meaning much less convenience for passengers.

When the demand is distributed to 9 CBD stations, they would require 3 sub-stops each to avoid saturation. Even 3 sub-stops is a lot for a CBD. Given these results, ITDP suggests that full BRT infrastructure also be built along Kenyatta through the CBD, including at least 2 stations along the Kenyatta link, to further disburse this demand to more alternative stations, allowing us to make the remaining CBD stations smaller.

1 Project Background

The Africa office of the Institute for Transportation & Development Policy is responsible for preparing the Nairobi Ndovu/A104 BRT service plan.

1.1 The Ndovu/A104 BRT project

The A104 Highway project is part of the National Urban Transport Improvement Project (NUTRIP) being undertaken by the Kenya National Highways Authority (KeNHA) with the support of the World Bank. The A104 Highway is one of the most important roads in Nairobi, connecting the airport to downtown and serving critical long distance freight and passenger links (as below).
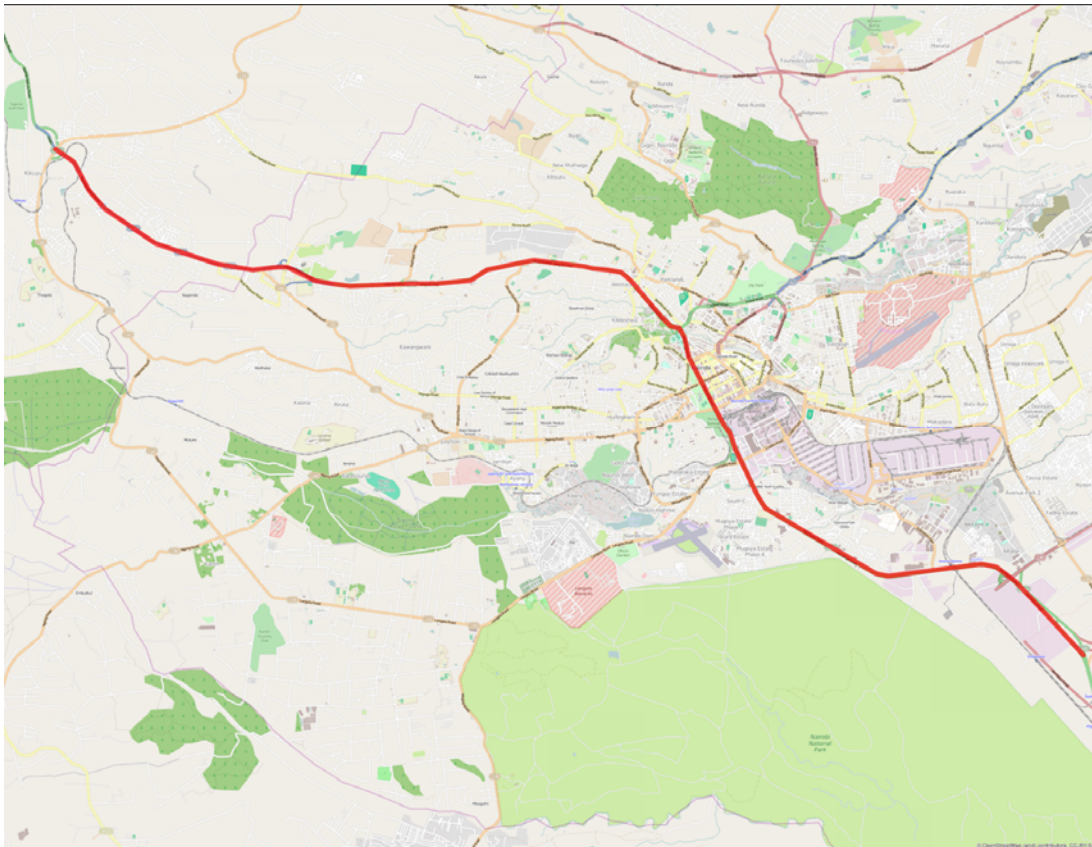
Figure 4: A104 Highway project

Responsibility for designing this road is split between three contractors: Lot 1 from JKIA to Likoni Road is under the purview of Gibb Africa, Lot 2 from Likoni Road to James Gichuru Road is under the purview of COWI, and Lot 3, from James Gichuru Road to Uthiru is under the purview of Eser (Turkey).

The Feasibility Study for Mass Rapid Transit System for the Nairobi Metropolitan Region (CES/APEC, 2011) that was commissioned by the Ministry of Transport recommended a mixed LRT and BRT system for further

detailing. The Nairobi Railway Station – JKIA – Athi River and the Nairobi Railway Station – Kabete – Kikuyu were among the 9 corridors identified to be appropriate for a Mass Rapid Transportation System.

In 2013, KeNHA thus made the decision to retrofit the A104 highway designs to include world-class Bus Rapid Transit (BRT). The plans are for high-quality – possibly gold-standard – BRT infrastructure along the A104. KeNHA's current plan is to build BRT infrastructure from the City Cabanas interchange to James Gichuru Road, maintaining ample road reserve for an extension of the BRT to the north in the future.

Figure 5: A104 BRT infrastructure as defined by KeNHA (also, Infrastructure Scenario 1, as below)

However, many of the decisions on BRT design were made prior to developing a service plan for the project. While it is a good idea to have some sense of what the design will be and where BRT infrastructure should be built, only a service plan can tell you where BRT infrastructure is most needed and how intersections and stations should be designed to accommodate the BRT services.

1.2   What is a service plan

The starting point for the design of a BRT system should not be the infrastructure or the vehicles. Instead, the system should be designed to achieve the operational characteristics that are desired by the customer. From the customer's perspective, some of the most important factors affecting their choice of travel modes are

whether the services will take them where they want to go and how long it will take. The starting point for the design of the best BRT systems has therefore been the creation of a service plan.

A service plan tells you how buses should be routed onto and off of the BRT corridor to bring passengers to their destinations with as few transfers as possible. It specifies bus routes, schedules, locations and sizes of BRT stations, number of buses needed, and technical specifications for the buses. It also tells you how what the ridership will likely be on each route, where passengers will board and alight, and how the existing bus and matatu routes will be impacted by the BRT.

Because of this, a service plan will affect many aspects of the BRT design and planning process:

1. **Placement of Dedicated Bus Lanes**: A service plan will guide the placement of dedicated lanes. Because a service plan will tell you where buses should be routed, how many should be placed on each route, and how current speeds differ from what can be achieved with BRT, it will indicate where dedicated lanes would be most effective.

2. **Intersection Design:** A service plan will also drive the design of intersections. For example, if half of the buses are exiting Uhuru Highway at Haile Selassie, that intersection will need to be designed to handle these turning volumes from the busway.

3. **Station Design:** A service plan will drive BRT station design because the services provided will affect the number of passengers boarding and alighting at each station and this in turn will affect the size of the stations, and particularly, the number of sub-stops required to avoid station saturation. If there are certain segments of the trunk BRT which have multiple bus routes operating on them (which the service plan will show), then certain stations will need to be designed to handle multiple buses docking at the same time.

4. **Feeder Stations:** A service plan will tell you whether it will be necessary to bring feeder buses to access the trunk corridor. If so, the BRT design will need to include feeder stations so that these buses may drop off passengers and turn around. A service plan will also tell you whether it makes more sense to bring feeder buses directly onto the trunk corridor (called "complementary" services) and if so, a feeder station will not need to be designed.

5. **Existing Bus/Matatu Routes:** A service plan will tell you, for each bus or matatu route, whether it will need to stop operating or be rerouted since it is not in the interest of a BRT system to allow matatus to continue operating in competition with the BRT. Therefore, a service plan must be done prior to implementing any strategy for handling the impacted matatu and bus owners.

6. **Financial Modeling:** A service plan will tell you how many passengers will use the system and how many buses will be needed. It is, therefore, a key input into a BRT system's financial model. The number of passengers will help determine what fare/tariff can be supported and the number of buses will help determine the cost of the system and the amount of equity that will likely need to be raised by shareholders.

It is therefore important that the service plan happen prior to many other critical decisions in the BRT planning, design, and financial modeling process. However, once design and financial modeling begins, it is generally necessary to go back and update the financial model to reflect certain design and financial decisions. Therefore, though the service plan must be the first step, service planning does not end once design begins. Rather, it must happen in an iterative way, being frequently updated to reflect changes in the infrastructure design and financial model.

1.3 MRTS Harmonisation Study and the Ndovu/A104 BRT Corridor

In 2014, the Ministry of Transport and Infrastructure, together with their consultants, Gauff, completed the MRTS Harmonisation Study. The aim of the study was "to bring together all previous studies and plans and to develop an integrated public transportation network for Nairobi and the Nairobi Metropolitan Region (NMR). The Harmonisation Study consists of two major parts."[1] The MRTS Harmonisation Study recommended five MRTS lines with a focus on BRT.

Figure 6: Five BRT lines proposed by the MRTS Harmonisation Study. Source: "Rail & Road Based Mass Rapid Transit System on Jogoo Road Corridor, Results of the Harmonisation Study Stakeholder Presentation". Gauff Consultants. May 16, 2014

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[1] Gauff Consultants, Mass Rapid Transit System Harmonisation Study Nairobi Metropolitan Region, 2014.

Further, it concurred with the choice of BRT on the A104 to become Line 1. However, it recommended a different extent of BRT infrastructure than is currently being designed by KeNHA. The Harmonisation Study's Line 1 BRT infrastructure has been defined as follows:

Figure 7: Ndovu/A104 BRT infrastructure as found in MRTS Harmonisation Study (also, Infrastructure Scenario 2, as below)

The Harmonisation Study is relevant to this service planning effort in that it attempts to define a basic service plan that should be adopted for all BRT corridors. However, it defined this service plan based on very macro-level data and did not involve a detailed data collection or modeling process. Therefore, ITDP has tested the Harmonisation Study's service plan for the Ndovu/A104 corridor as one of the scenarios but did not limit its scenario testing to only this scenario since such a scenario, in our experience, limits the benefits of the BRT system and thus, negatively impacts the ridership. The service plan defined by the Harmonisation Study is described in detail and tested in Section 5.5.3.

2   Objectives of this assignment

ITDP is a non-profit whose core competency is in providing technical support for BRT projects and has helped to design service plans for many of the best BRT systems around the world. As such, ITDP is working with KeNHA to create the service plan for the Ndovu/A104 BRT corridor. The objective of this work is to provide

operational design for the first corridor of a high quality, high capacity bus rapid transit (BRT) system in Nairobi, Kenya.

2.1 Personnel and timeframe

ITDP's service planning work in Nairobi was carried out from October 2013 to present and included the following experts:

Annie Weinstock
Walter Hook
Stephanie Lotshaw
Christopher Van Eyken
Elkin Bello
Christopher Kost
Zhu Xianyuan
Remi Jeanneret
Jacob Mason

3 Existing Conditions

A well-designed service plan is based on a careful evaluation and understanding of the existing bus and matatu services that are currently serving public transport passengers in the area impacted by the new BRT. It is these passengers most likely to transfer onto the BRT and these passengers who will make up the majority of future BRT users.

In order to model existing conditions for public transport use on the A104, ITDP collected real data along the corridor through a series of surveys, as described below. This became the basis for modeled simulation of baseline conditions, and later for modeled demand estimates of future use of the BRT.

3.1 Surveys

In October 2013 and February 2014, ITDP completed all of the necessary surveys and data collection:

- Boarding & alighting surveys for 48 routes, with at least 5 samples for each route in each time period (AM peak);
- Matatu frequency & occupancy surveys at multiple locations;
- Matatu stop transfer surveys;
- At-station boarding and alighting surveys; and
- Speed and delay surveys

The Nairobi agencies provided excellent assistance in the form of:

- Awareness raising amongst the general public via radio, television ads and notices; and

- Support from the Police and local authorities.

3.1.1 Identifying the affected street network and bus routes

In order to carry out the data collection survey, ITDP first identified the "affected street network". This refers to the streets within the Nairobi street network which carry matatu and/or and bus routes that interact with the A104 corridor. This includes:

- Streets which intersect A104,
- Streets which run parallel and near to A104, A104 itself, and
- Streets in the CBD.

We also included additional survey locations beyond this area to better identify the city's passenger demand behavior.

Prior to conducting the survey, it was essential to identify the current itinerary for each route and the registered stops (designated or non-designated). As in many African cities, Nairobi's matatu routes are subject to frequent modification, undermining reliability for passengers. While most routes have a definite origin and final destination, the itinerary each matatu takes can vary daily or even hourly due to congestion, construction, and the presence of the traffic police. Even a matatu's origins and destinations can change – for example, if a matatu stage is crowded and drivers relocate to different parks. That said, a basic sense of the routes is critical to understanding existing public transport patterns on the corridor.

The University of Nairobi/Columbia University/MIT team did a comprehensive analysis of Nairobi's matatu routes compiling the existing stopping locations both designated and non-designated for a total of 118 routes. We used this map as a starting point and identified the existing routes and registered stops in the affected network so that we could select routes and points for performing the on-board and at station boarding and alighting survey.
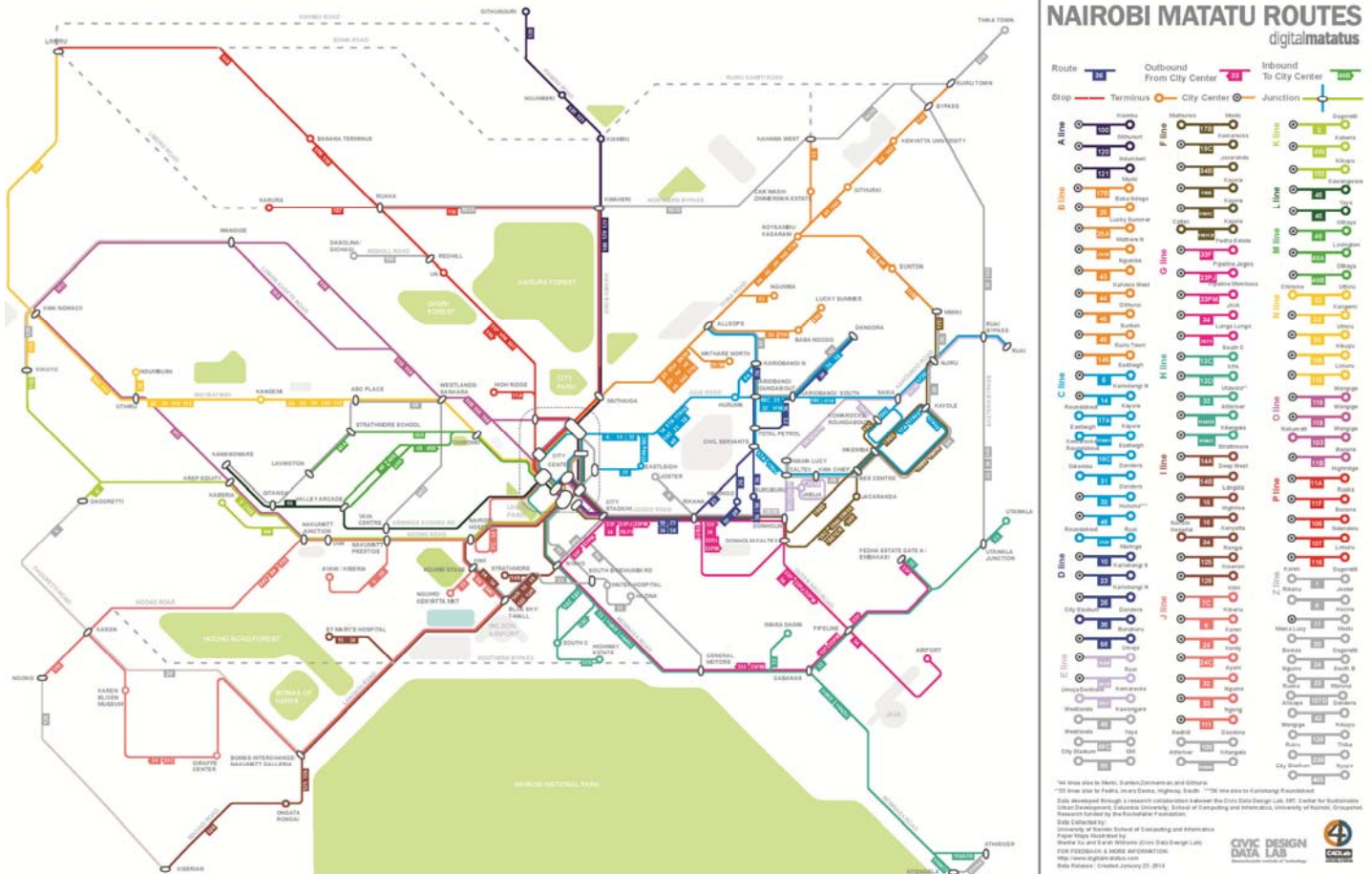
Figure 8 Map of Nairobi's matatu services. Source: Digital Matatus

Using this map as a starting point, we identified the matatu routes which interfaced enough with the corridor that they should be initially considered for the BRT service plan. It was for these routes that we performed a detailed survey. This selection considered three main categories:

1) Route frequency (routes with greater than 3 buses/hour),
2) Route overlap (routes with at least 20% overlap on the A104 corridor), and
3) Area of influence analysis (routes near the corridor that could eventually be captured by a BRT).

A total of 48 routes were selected for the surveys. Some routes were identified to operate along parallel corridors and thus marked as important under the "area of influence" aspect (item #3).

The maps below show all of the routes surveyed as part of ITDP's A104 survey.

Figure 9: Surveyed routes operating in the wider Nairobi area.

Figure 10: Surveyed routes operating in the Central Business District.

3.1.2 On-board and at-station boarding and alighting (BA) surveys

The boarding and alighting (BA) survey is a careful mapping of precise matatu stopping locations, as well as a count of how many passengers get on and off a matatu or bus at each stop along the route. Two methodologies are commonly used to carry out BA surveys:

1. **Onboard BA surveys** which requires surveyors to ride a route (in full or partially) and count numbers of passengers boarding and alighting at each stop.
2. **At-station BA survey** which requires surveyors to record passenger movements per route at a given physical location or stop.

At-station BA surveys require less staff but are considerably more difficult to process and adjust, while on-board BA surveys provide a more consistent and easier to process dataset. The at-station methodology is useful when a high volume of routes is observed along the corridor where the BRT services and infrastructure will be implemented. This survey was carried out using the "onboard" methodology. However, on and off volumes were captured at the central stretch of routes with long itineraries where the highest demand occurs.

3.1.3 Bus frequency & occupancy surveys

A Frequency and Visual Occupancy (FVO) survey is a survey of how frequent each bus or matatu route runs and what the approximate occupancy is of each vehicle. This shows existing demand on the matatu network. We initially selected 78 points for this survey. At each point, one or two surveyors (determined based on approximate expected bus frequencies at each survey point) recorded the matatu route and assessed the capacity and occupancy level.

The image below shows the locations where the FVO was carried out.
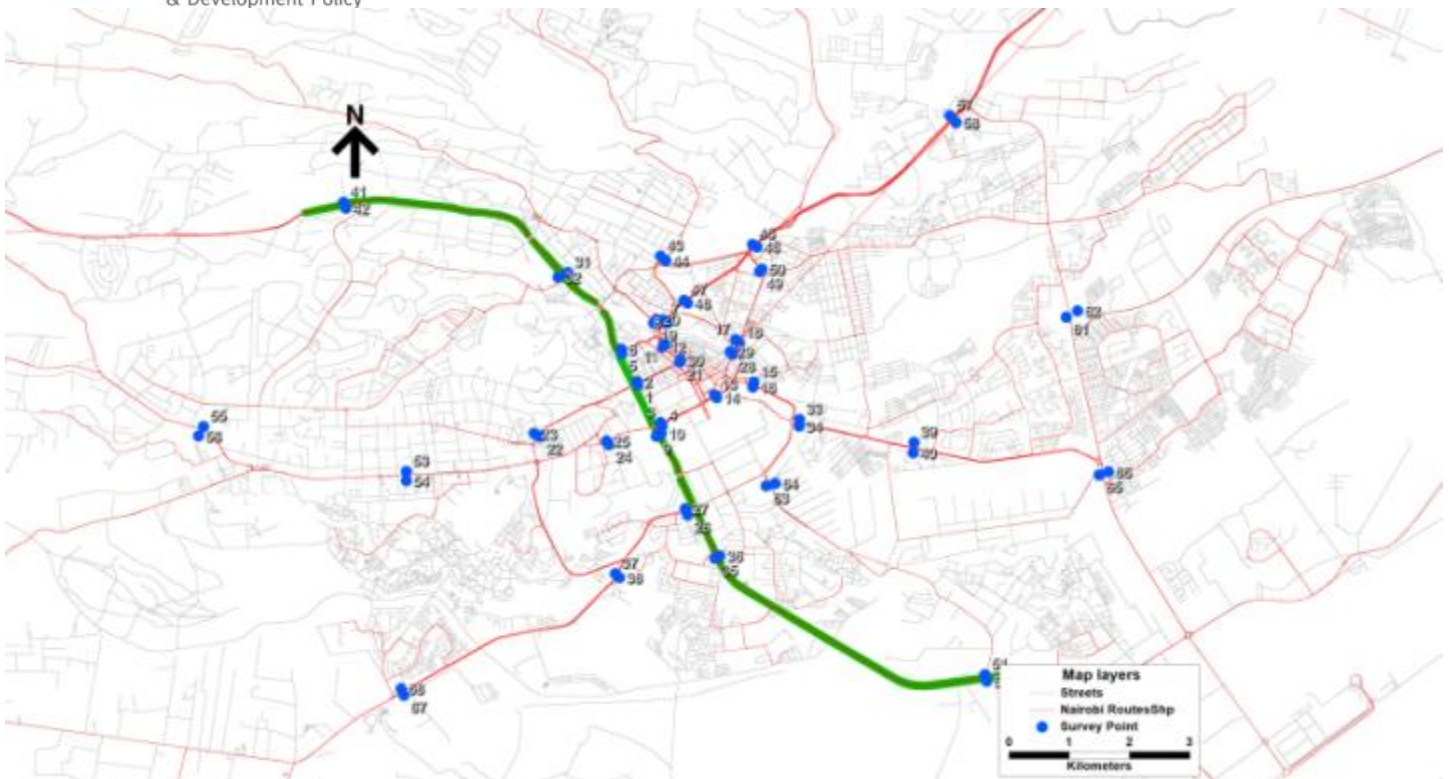
Figure 11: FVO survey locations for Ndovu/A104 BRT service planning data collection. Source: ITDP

3.1.4 Bus passenger transfer surveys

The data collected during the BA survey provides passenger behavior on a single route by single route basis. However, many passengers make their full trip using more than one route. A transfer survey is helpful in order to get a better sense of full passenger trips, including trip origin and trip destination, beyond a single route.

We selected the following strategic locations to question passengers about their trip patterns:

- Belleview bus stop,
- Nyayo bus stop,
- GPO bus stop,
- Africa International University,
- Railways bus stop,
- Nairobi bus station,
- Kencom bus stage,
- Odeon bus stage,
- Westlands bus stage,
- 34 bus station,
- Church Army bus stop, and
- Jogoo Road Railway station.

These were chosen based on the results collected in the other surveys. At these points, surveyors asked how did passengers get to the survey point and where will they go from here as well as questions about how they arrive at their start point, how many transfers they make, and the total cost of their journey. The figure below shows the locations of the bus passenger transfer surveys.

Figure 12: Transfer survey locations for Ndovu/A104 BRT service planning data collection. Source: ITDP

4 Existing (baseline) conditions

A full picture of current public transport patterns along and near the A104 corridor is a critical first step to determining who will ride BRT services and what the most important routes and areas are to serve. We therefore processed the survey data and placed the results in maps and tables in order to best convey existing peak hour travel patterns.

4.1 Existing frequencies

Matatu frequencies along the A104 are high, with the average matatu routes operating at a frequency of one matatu every 3 minutes in the peak hour. The frequency per route surveyed is shown below.

OUTBOUND (AWAY FROM CBD)				INBOUND (TO CBD)			
Route	Frequency (buses/hr)	Route	Frequency (buses/hr)	Route	Frequency (buses/hr)	Route	Frequency (buses/hr)
2	32.8	33PJ	39.3	2	29.4	34B	28.0
4W	11.8	33PM	20.0	4W	13.4	34JK	18.0
7C	22.5	34B	4.0	7C	41.0	46KW	58.0
8	33.7	34JK	18.0	8	53.3	46YA	77.2
11	15.3	46KW	32.3	11	26.3	48A	28.1
11A	15.7	46YA	32.5	11A	15.7	48B	4.5
11B	17.3	58	6.3	11B	21.3	48KW	10.0
12C	6.2	69	142.0	14A	10.1	48OT	12.0
12D	2.5	102	15.4	14B	4.0	58	6.8
15	51.9	105	57.5	19C2	27.0	69	29.7
16	9.8	110A	15.3	24c	39.1	102	16.9
19C2	28.5	111	30.7	30	32.5	110K	13.7
23KN	59.3	115	4.5	32AY	13.0	111	29.0
24	6.4	118	5.0	33CA	20.0	118	12.5
24C	39.1	119	10.8	33IM	29.9	119	14.0
32AY	20.0	3839	13.1	33MK	9.5	125	32.4
33CA	20.0			33NG	60.0	126	10.0
33FE	26.8			33PJ	26.0	3839	17.5
33NG	39.3			33UT	30.8		

Table 5: Frequency counts of surveyed routes. Source: ITDP Survey

If we look at the aggregate bus frequencies by road in the study area, we find that the highest frequencies (greater than 400 buses in the AM peak hour) are on Haile Selassie Avenue in the CBD. Frequencies almost as high are experienced on Kenyatta and on the segments of roads nearest the CBD.
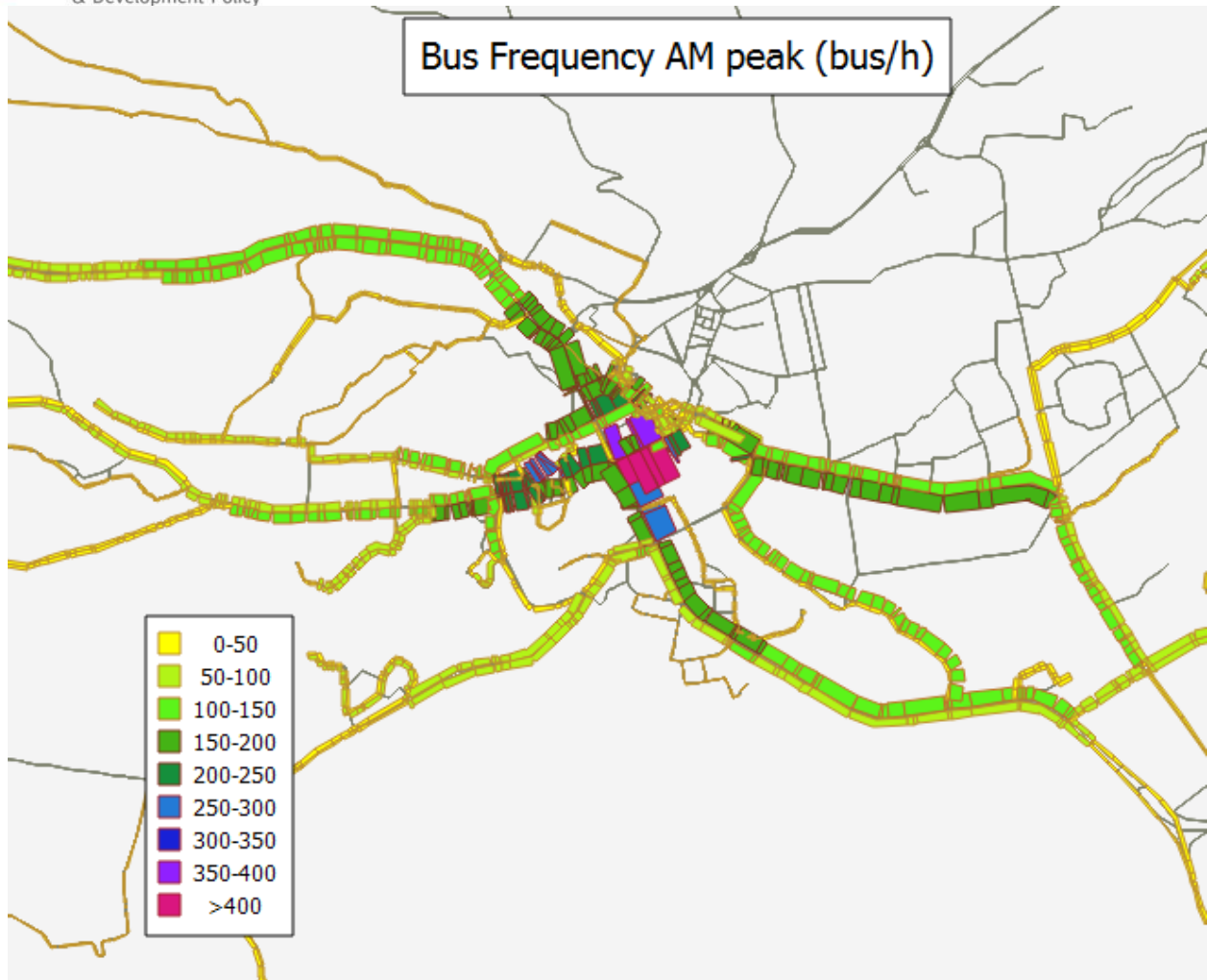
Figure 13: Existing aggregate matatu frequencies for all routes surveyed during AM peak hour.

4.2 Existing public transport speeds

The map below shows existing bus speeds on all of the streets where surveys were conducted. Unsurprisingly, the slowest speeds are nearest the city center, and inside of the city center, while the speeds get faster farther away from the city center. On the A104, the slowest speeds are found between Langata Road and the Westlands Roundabout. Within the city center, all roads suffer very slow speeds.
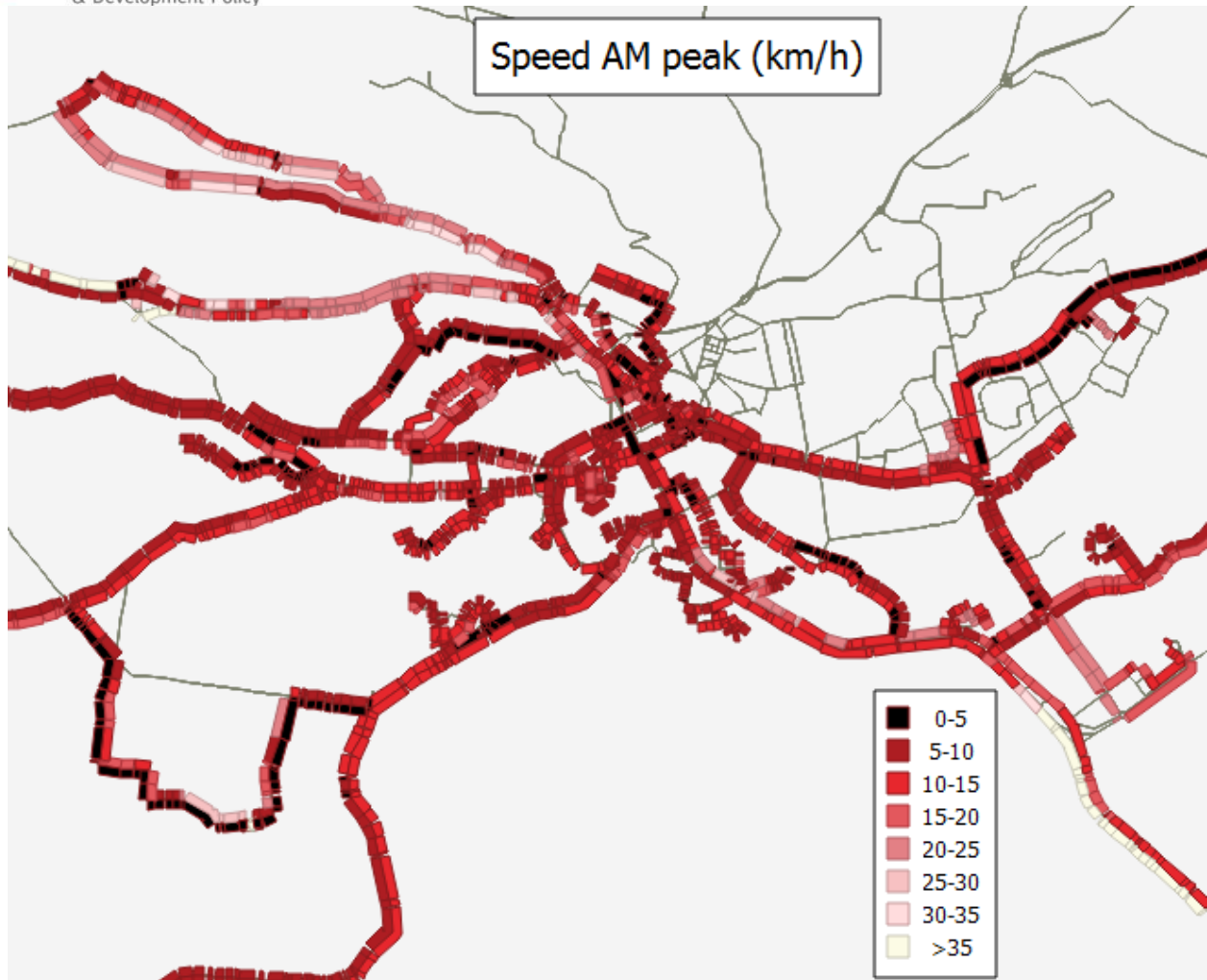
Figure 14: Existing average matatu speeds for all routes surveyed. AM peak hour

4.3 Existing public transport passenger demand

The map below shows existing stop-by-stop boarding and alighting volumes for all matatu routes surveyed. The orange triangles pointing up represent boardings and the purple triangles pointing down represent alightings. It shows that the most boardings and alightings happen in the CBD, particularly on the eastern side. Because the survey was for the AM peak hour, there are more alightings in and near the CBD than boardings.

This map is important as it shows where most passengers are actually going. As we design BRT service scenarios, as described in the sections to follow, we attempt to route services where passenger demand actually is.
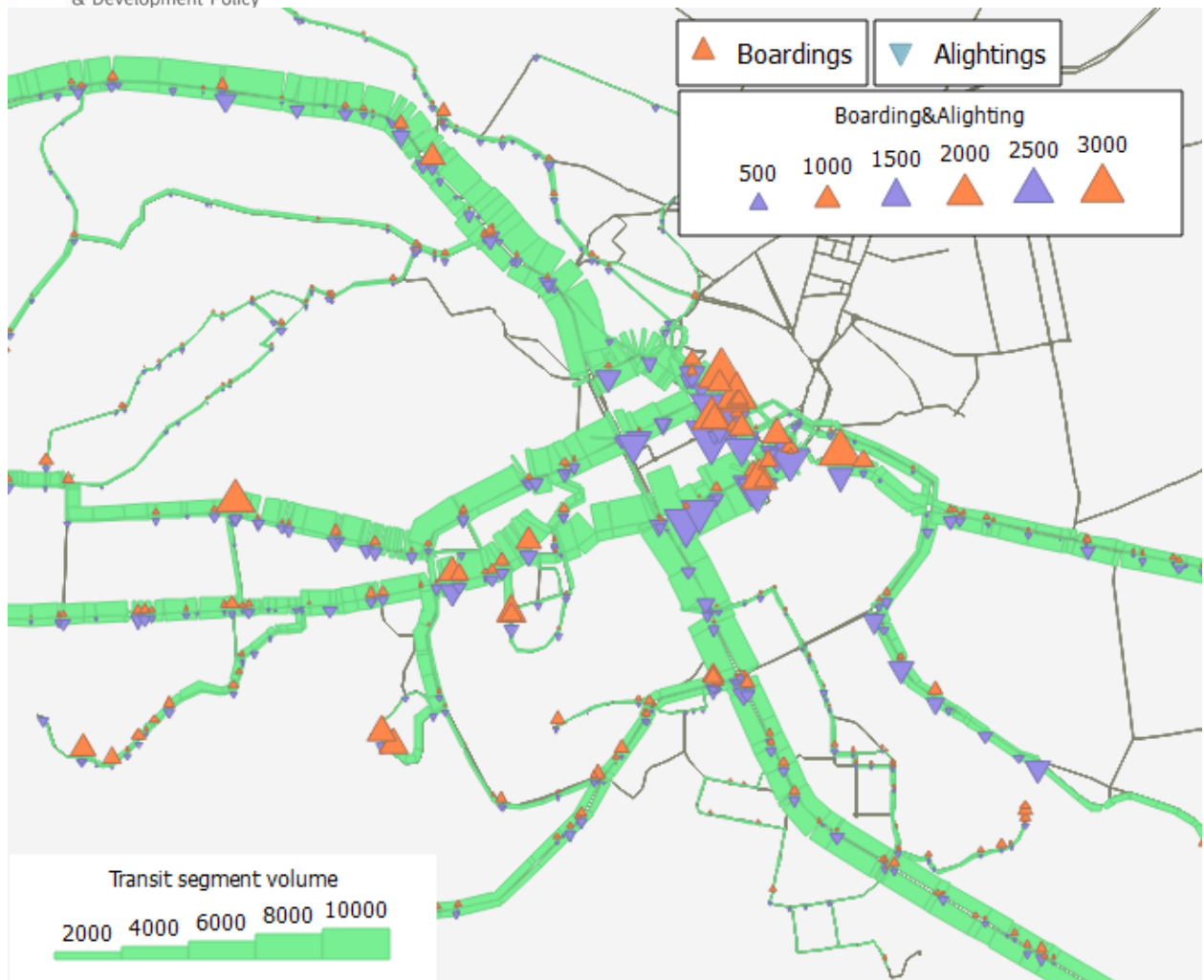
Figure 15: Existing stop-by-stop boarding and alighting volumes for all routes surveyed. AM peak hour.
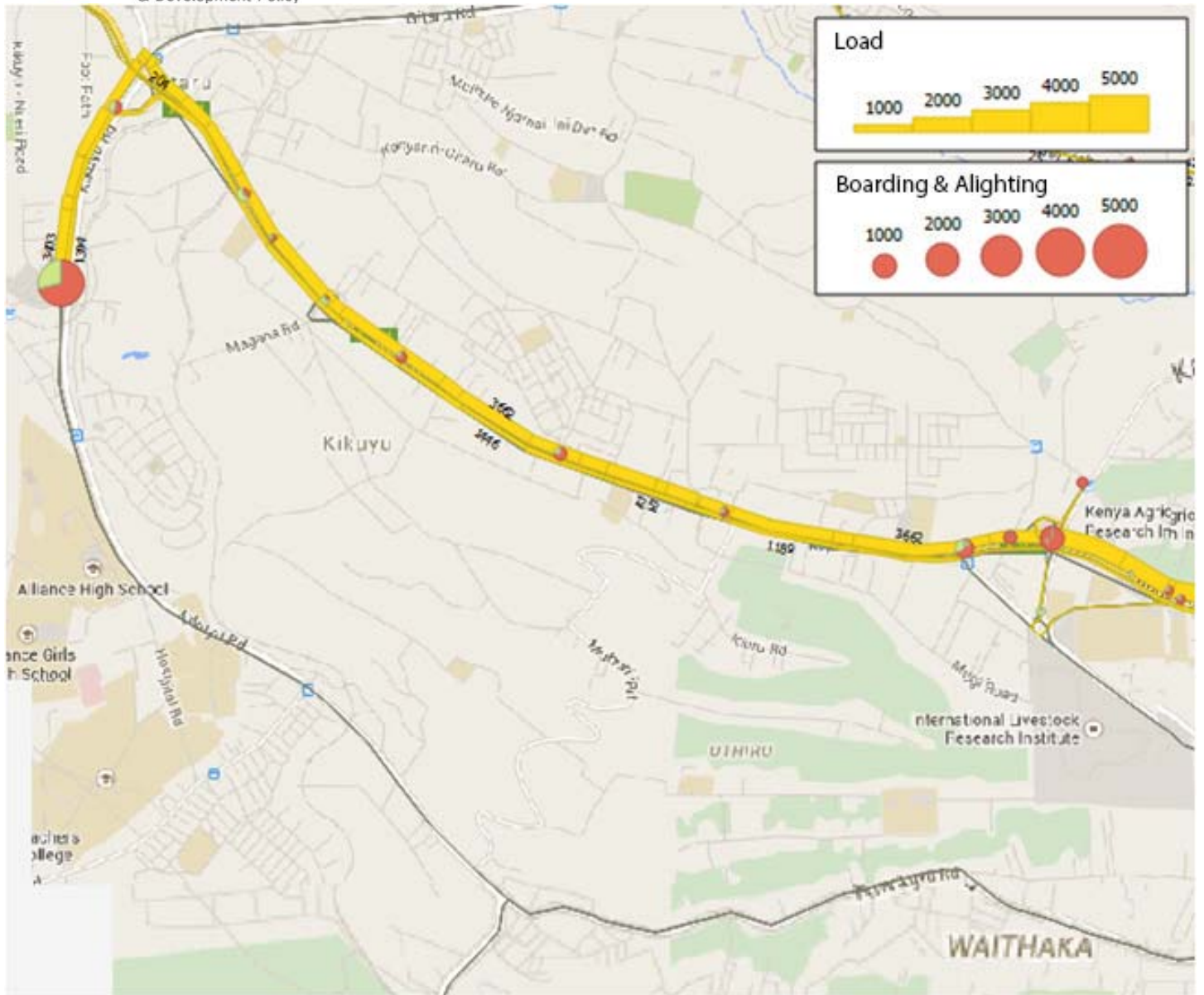
Figure 16: Existing matatu loads on A104 northern segment from Naivasha Rd to Kikuyu Rd, AM peak hour.
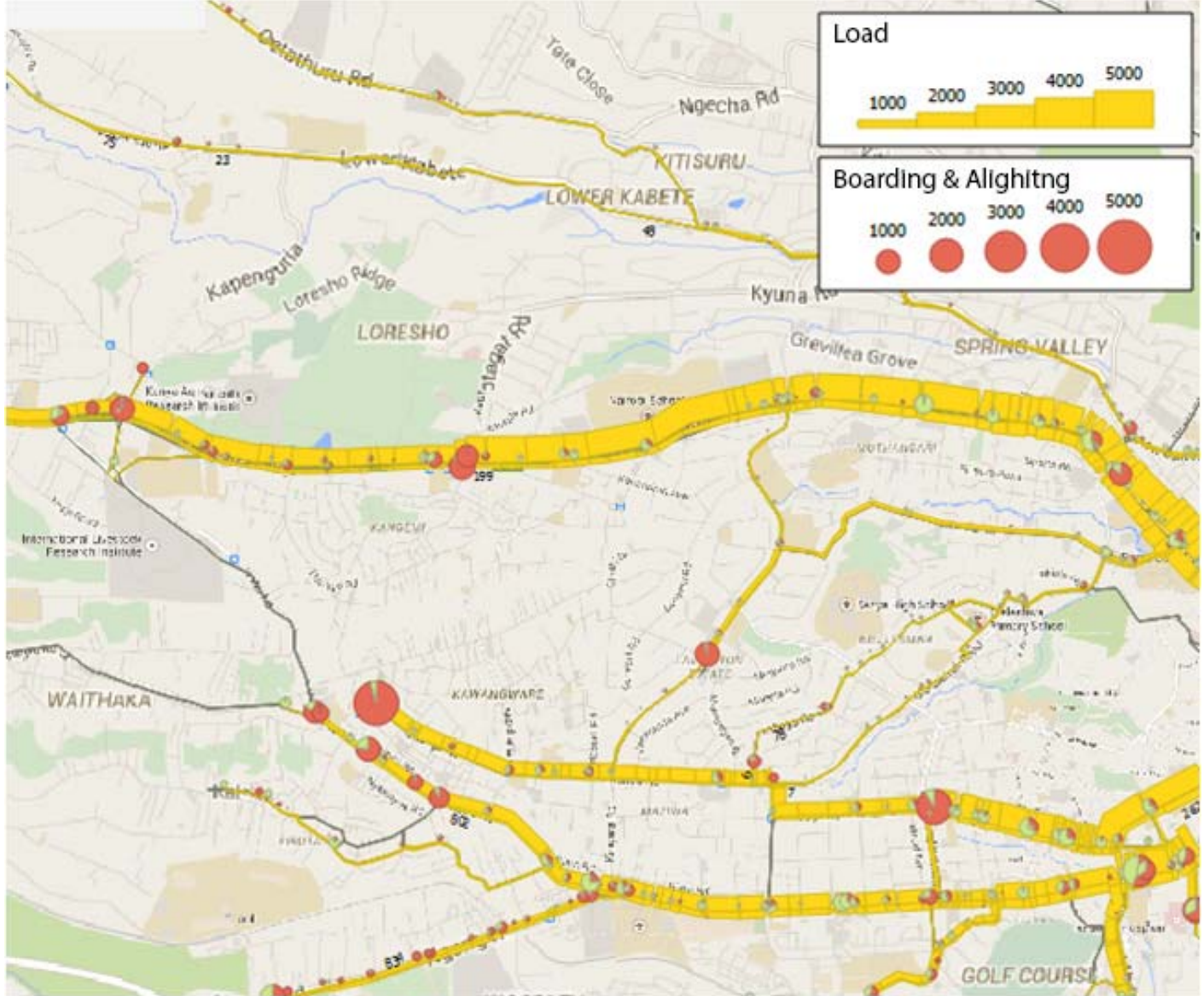
Figure 17: Existing matatu loads on A104, from Naivahsa Rd to Westlands Roundabout AM peak.

Figure 18: Existing matatu load on A104 corridor and CBD, AM peak hour.

The peak hour ridership is also high with an aggregate ridership of 10,346 passengers per hour per direction (pphpd) just north of the CBD (headed southbound into the CBD) and 8,564 just south of the CBD (headed northbound into the CBD). This pphpd occurs on Uhuru Highway just north of the CBD in the southbound direction where many matatu routes operate and demand is high.
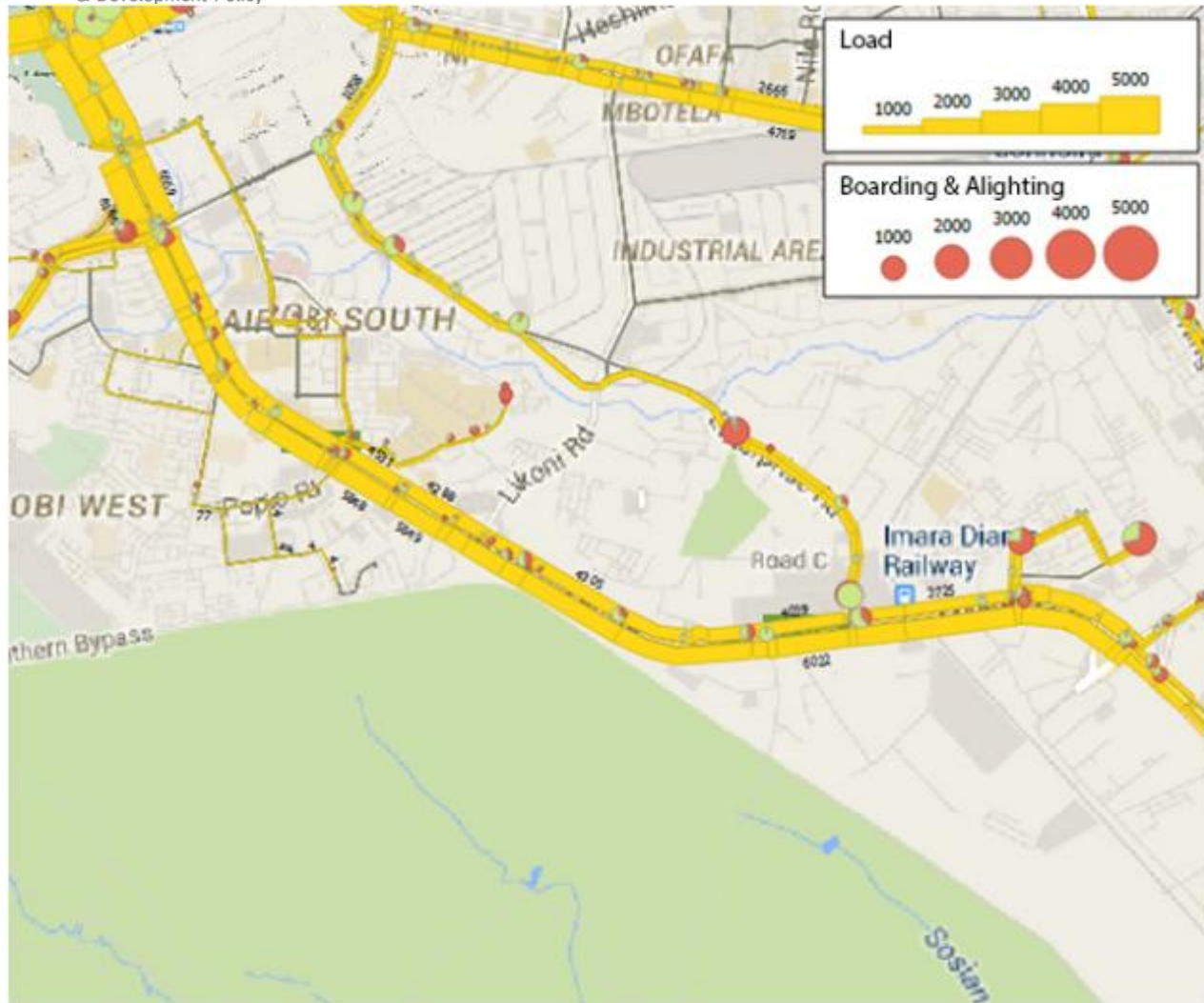
Figure 19: Existing matatu loads on A104 corridor, south of CBD to Imara Diama Railway.
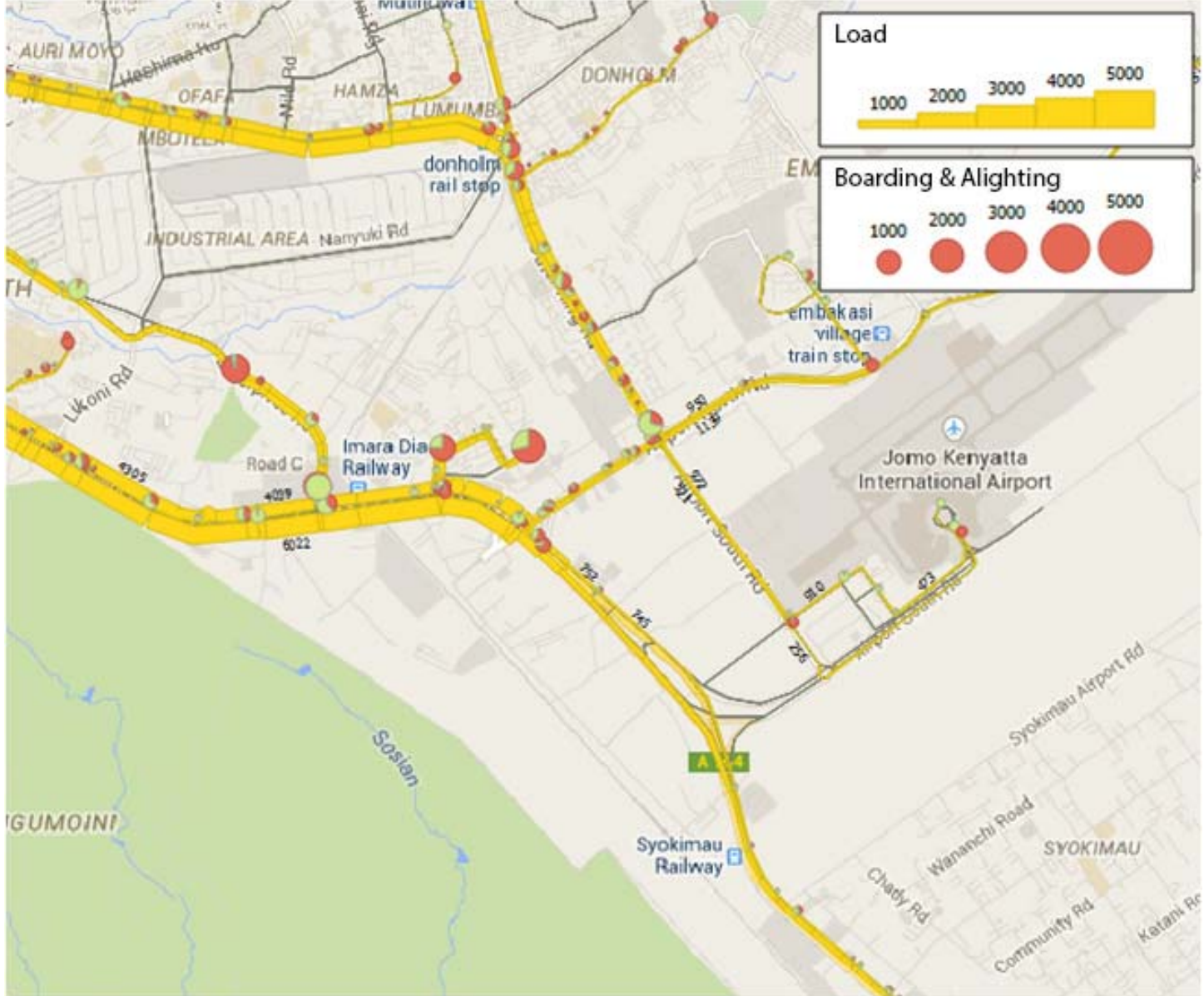
Figure 20: Existing matatu loads on A104 corridor, approaching airport, from Likoni Rd to JKIA. AM peak.

5   Service plan for the Ndovu/A104 BRT

5.1   Modeling process

Using all of the existing conditions information shown in the previous section, we then built a public transport model for the corridor. This model allows us to provide a reasonable estimate, grounded in actual data, of BRT ridership under a variety of service scenarios. Because this model is based on *actual existing* transport data collected in the field, it is more reliable than a model which looks only at population and employment and makes broad assumptions about trip-making.

The figure below provides an overview of the modeling process carried out by ITDP in Nairobi.
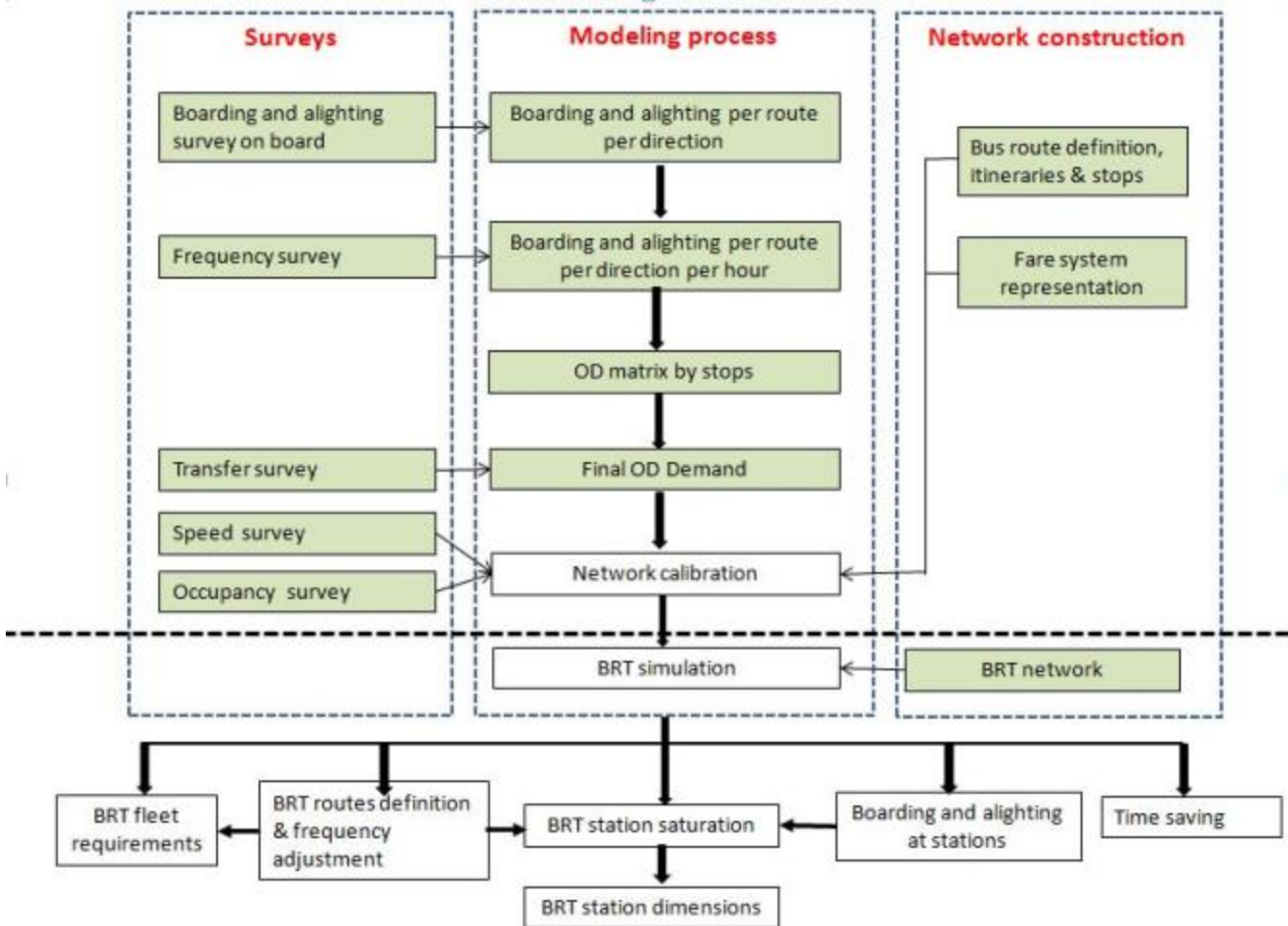
Figure 21 Overview of survey, modeling and BRT service plan process.

In order to build a model, we first replicated the relevant portions of the Nairobi street network in our model, using the modeling software package Emme 4. On the street network, we then coded the existing peak hour speeds, as collected.

In order to model existing trip patterns, we then used the stop-by-stop boarding and alighting data and converted it into full trip origin-destination pairs. That is, the surveys allowed us to count how many people were boarding at one station (e.g., Nyayo) and how many people were alighting at another station (e.g., Railways). But this kind of survey does not tell us how many of the people boarding at Nyayo are alighting at Railways. We do not know where the passengers boarding at Nyayo alight.

We therefore used what is called a Fratar distribution model[2] in order to transform the boarding/alighting survey into a stop-to-stop "trip matrix." A Fratar model is a probabilistic tool which estimates how many passengers boarding at one specific station are alighting at another specific station. The result, therefore, is a stop-to-stop trip matrix.

The stop-to-stop matrix was then transformed into a full origin-destination (OD) matrix according to transfer survey data. However, the OD matrix at that point was only based on a survey sample of passengers boarding and alighting. To get the full OD matrix, we then related the number of people counted as boarding and alighting at each stop, to the total number of transit passengers per direction per hour at each survey point. The total number of public transit passengers in the peak hour was taken from the data collected during the FVO survey, in which we obtained actual data on hourly passenger trips passing checkpoints. We thus expanded this OD matrix by the actual number of passengers using the system in the peak hour.

Once we had completed this, we were ready to begin modeling future scenarios. A BRT service scenario is modeled by increasing the speeds on the road links where BRT infrastructure is expected since passengers in the model make their future travel choices based on finding the fastest overall trip. We then added a set of BRT routes ("BRT service scenarios") to interact with the BRT infrastructure. However, not every scenario assumes the same build-out of BRT infrastructure. We therefore also defined "BRT Infrastructure Scenarios" (see Section 5.4 below).

Finally, we made the assumption, based on standard practice, that matatu routes that compete directly with a BRT route would be cancelled and therefore removed it from the model as a travel option. Depending on the BRT service scenario, some passengers will choose to use the BRT and others will seek an alternate route using matatus (again noting that modeled passengers would have to seek a more circuitous matatu routing due to the fact that direct matatu competition has been eliminated from the mode). BRT services were assumed to carry a fare of 70 Ksh while matatu services were assumed to carry a fare of 50 Ksh. We seek to find the scenario that attracts the most passengers at the lowest generalized cost per passenger to the city.

5.2 Model calibration

The survey results were placed into Emme IV and a transit demand model was created. The model was calibrated in two steps: First, we calibrated the modeled demand for each of the matatu routes using the A104 for which boarding and alighting data was collected and compared to link specific demand calculated from frequency and occupancy surveys. This yielded a very high goodness of fit (R2) of .964.

In Figures 22 and 23 below, each blue point represents one location where a frequency and occupancy count was done, as shown on the map on p.26 (Figure 11). The y-axis shows the passengers per hour per direction (PPHPD) predicted by the model at each of the frequency and occupancy survey points shown on the map

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[2] National Cooperative Highway Research Program, *Travel Demand Forecasting: Parameters and Techniques,* 2012

(Figure 11). The x-axis shows the actual observed PPHPD from the survey at each of the same points. When these two figures match exactly, the blue point should fall exactly on the diagonal blue line. The deviance from this line is what is measured by the R2.

If the same map were created for the calibration of the model used in the MRTS Harmonisation Study, for instance, there would only be two blue points, as they only calibrated their model with two locations, not enough to be statistically significant.
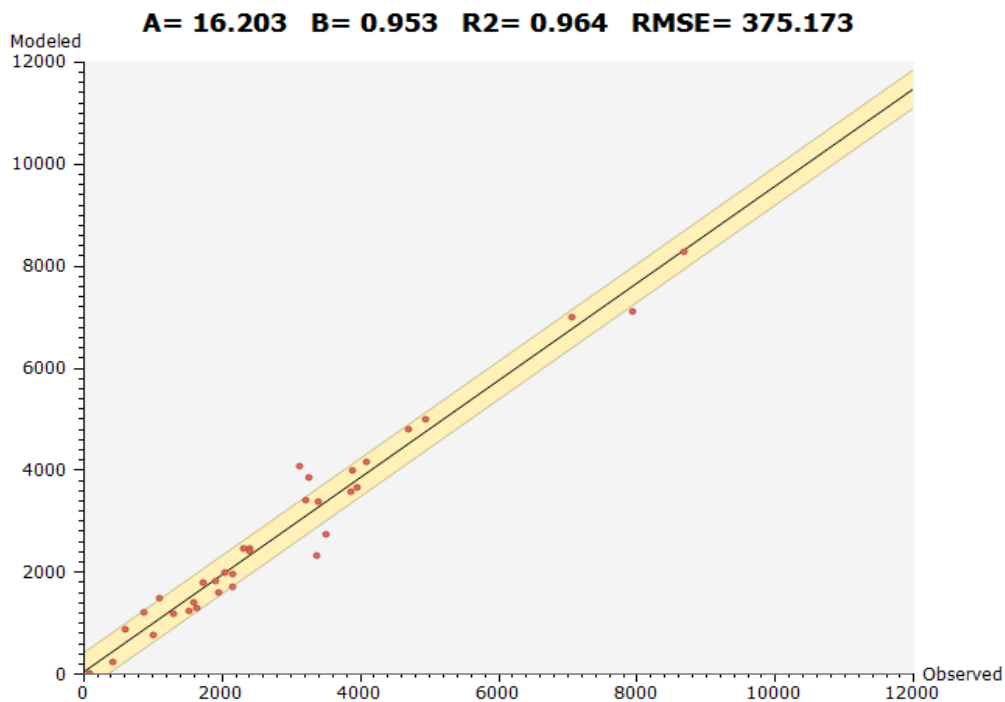
Figure 22: Calibration of model for existing matatu routes on A104 yielded a very good R2 of .964

Second, the modeled results were compared to the frequency and occupancy counts for all the routes along the A104 and Langata. This yielded an acceptable goodness of fit (R2) of 0.875.

A= 364.429 B= 0.834 R2= 0.875 RMSE= 965.065
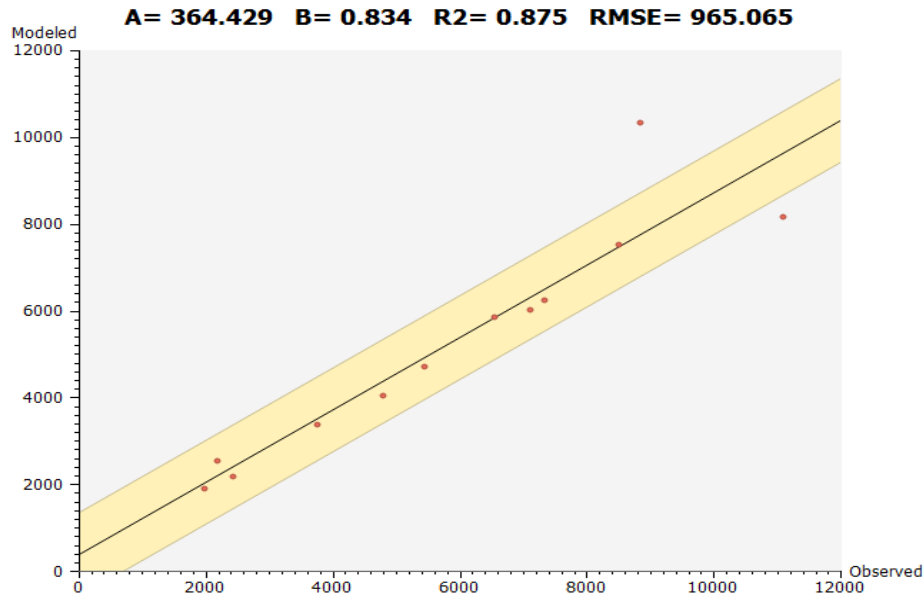
Figure 23: Calibration of model for existing matatu routes on A104 & Langata yielded an acceptable R2 of 0.875

5.3   General Objectives

General objectives for the modeling were:

- Accommodate as many passengers as possible,
- Adjust BRT routes to demand patterns. For example, add new services which more efficiently link the corridor with the CBD, airport, Kibera, and large employment centers in Nairobi.
- Include BRT infrastructure in additional locations if it helps greatly to improve a high-demand BRT service but minimize new infrastructure added.
- Minimize unnecessary turning movements at intersections both on A104 and in the CBD,
- Calculate station dimensions (length, width, and number of sub-stops), and
- Calculate BRT bus fleet requirements (size and number).

5.4   BRT Infrastructure Scenarios

Before testing a BRT service scenario, the extent of the BRT infrastructure on which the services in a scenario will run must be defined. This is because in the transit model, the links where BRT infrastructure will be placed will be coded with higher speeds. In this way, passengers will make their trip decisions based on selection of the shortest trip.

In testing service scenarios, one does not necessarily hold constant the infrastructure scenarios. These can be adjusted iteratively in order to find the best infrastructure/service combination. Of course, political and fiscal constraints may ultimately determine the extent of the infrastructure. However, where small changes in BRT

infrastructure yield large increases in BRT passenger volumes, it may be worth considering making these changes.

Before describing the BRT service scenarios, we begin by describing a set of BRT infrastructure scenarios. All service scenarios (below) are associated with one of these infrastructure scenarios.

5.4.1   Infrastructure Scenario 1

Infrastructure Scenario 1 is the extent of the infrastructure that KeNHA is currently planning to build. The BRT infrastructure sits on A104 only and extends from the City Cabanas interchange to the James Gichuru roundabout. Beyond the James Gichuru roundabout, space will be reserved for future BRT but will not be built immediately.
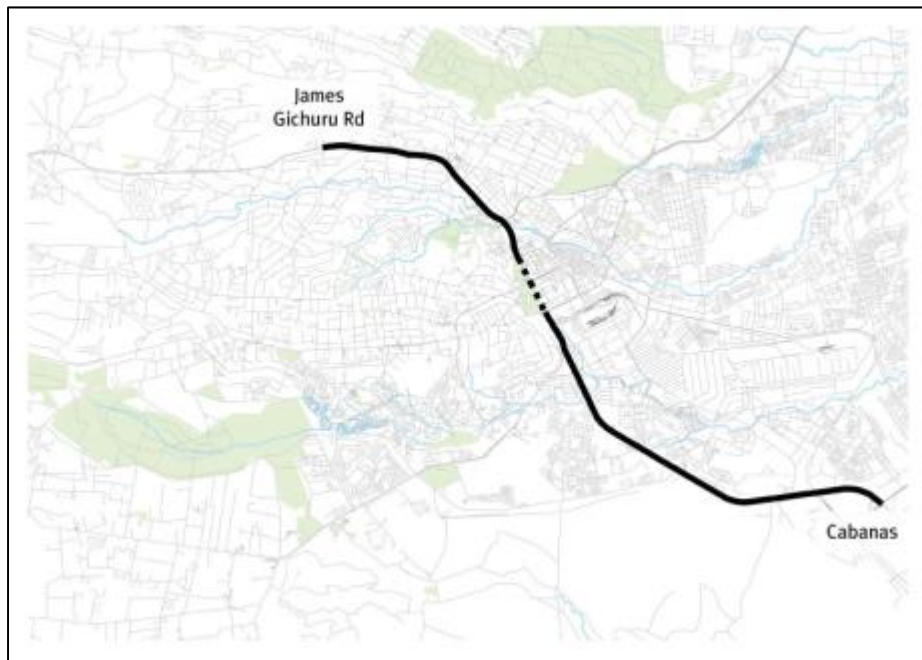
Figure 24: Infrastructure Scenario 1 - KeNHA's current design

5.4.2   Infrastructure Scenario 2

Infrastructure Scenario 2 is the extent of the infrastructure recommended by the MRTS Harmonisation Study. Like in Infrastructure Scenario 1, the BRT infrastructure will be built on A104 only but the length is greater, beginning at the Imara Diama rail station and extending to Uthiru.

Figure 25: Infrastructure Scenario 2 - MRTS Harmonization Study

5.4.3 Infrastructure Scenario 3

Infrastructure Scenario 3 is the KeNHA infrastructure on A104 (Infrastructure Scenario 1) plus a loop through the CBD. The CBD loop travels on Haile Selassie Avenue, north onto Moi Avenue, and across University Way back to A104. The CBD loop was included due to extremely slow travel speeds in the CBD plus a multitude of passengers currently traveling to CBD destinations.

Figure 26: Infrastructure Scenario 3 - KeNHA + CBD loop

5.4.4 Infrastructure Scenario 4

Infrastructure Scenario 4 is the KeNHA infrastructure on A104 plus the CBD (Infrastructure Scenario 3) plus a 1.5 kilometer stretch west on Langata Road to the Magadi Road junction. The stretch on Langata Road was included due to extremely slow travel speeds in the CBD plus a multitude of passengers currently traveling to CBD destinations.
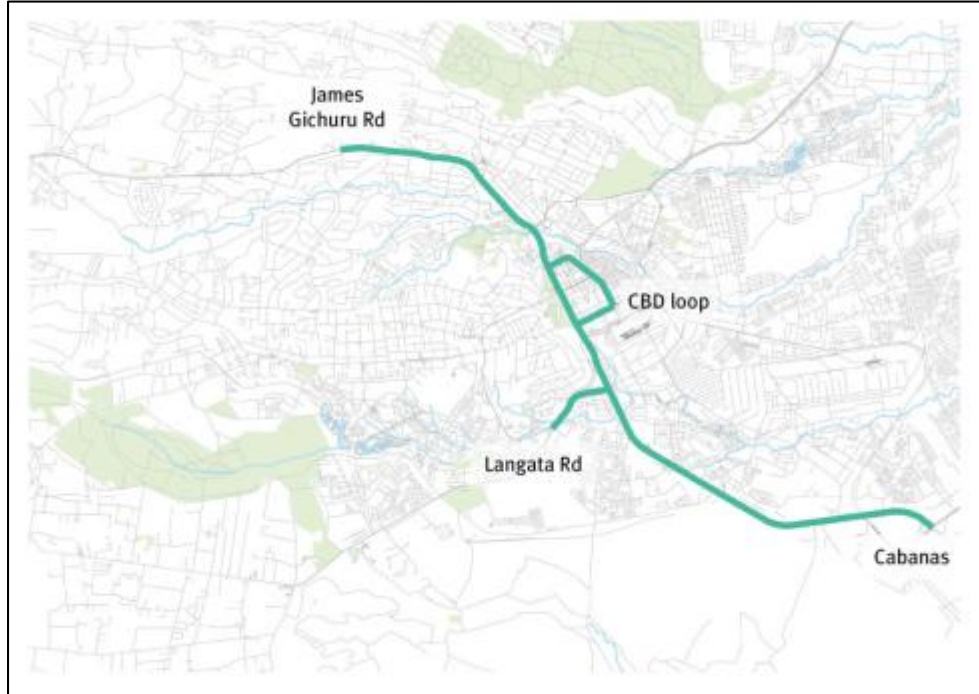
Figure 27: Infrastructure Scenario 4 - KeNHA + CBD loop + Langata

5.4.5   A note on BRT infrastructure through the CBD

Most of the boardings and alightings on matatus occur in the CBD. We saw in Figures 15 & 18 that the highest concentration of boardings and alightings for all routes surveyed were in the CBD. In fact, some observations of walking trips within the CBD revealed that most CBD trips are destined for points around Moi Avenue and east. This is shown in the figure below.

Figure 28: Trip generation density in Nairobi CBD. The numbers, found around Moi Avenue and to the east, indicate where the highest number of trips originate

In fact, the world's best BRT systems include full BRT infrastructure right through the CBD. This is the case in Bogota, Johannesburg, Mexico City, most recently Dar es Salaam, and many more.

Figure 29: Bogota's TransMilenio BRT goes right through the CBD

In Nairobi, modeling of the BRT corridor showed that if BRT infrastructure is not built through the CBD, many people would be forced to walk 0.7 to 1 kilometer to get to the BRT on Uhuru Highway. Yet in general, people are willing to walk only 0.5 kilometers at most.

Figure 30: Volume of walking trips along CBD streets if BRT infrastructure is not included in the CBD but only on Uhuru Highway

Therefore, we recommend prioritizing the service scenarios (below) which operate on either of the two infrastructure scenarios which include the CBD (i.e, Infrastructure Scenarios 3 & 4). This includes BRT Services

Scenarios III, IV, and V. As we will, see, these scenarios perform better than Service Scenarios I and II which do not include BRT infrastructure in the CBD.

5.5 BRT Service Scenarios

5.5.1 Inclusion or exclusion of routes

The determination of which routes to include in the service plan is based, first, on existing public transport trip patterns. The existing matatu and bus routes serve as good proxies for transit demand patterns in Nairobi. Matatus are, to a great extent, routed as they are to respond to the needs of the public transport-traveling public. Therefore, there is some logic to the existing matatu routing patterns. People are also accustomed to these routes. Therefore, we make our initial service planning decisions with some correlation to the existing routings of the matatus and buses already operating in Nairobi. By analyzing the existing routings and demand of the matatus and buses, we can design and test a set of service scenarios. In order to make this determination, we use the following two criteria:

1. **Percentage existing route overlap with the corridor**: A route that has significant overlap with the BRT corridor is a good candidate for inclusion into the BRT system since the passengers that use that route today will benefit largely from BRT improvements. However, a route that is included as a BRT route generally requires the procurement of new fleet. Thus, if most of the trip for a route is operating off the BRT trunk corridor, the benefits of inclusion into the BRT service plan may not justify the bus procurement cost. We consider percentage overlap for each BRT Infrastructure Scenario as defined above as one criterion.
2. **Avoidance of redundancy**: There were often several routes serving very similar trip origins and destinations. BRT systems generally have routing structures that are simple enough to be easily understood by visitors and avoid redundancy.
3. **Avoidance of Station Saturation**: Our analysis shows that several downtown stations are likely to saturate unless four sub-stops are built. It may prove impossible to build this many sub-stops downtown, in which case routes that are particularly intensive users of the bottleneck stations will need to be selectively removed.

The above criteria are the most important factors for determining which routes should be included into the BRT system.

The below table shows each route surveyed, the frequency of the route (in buses/hour), and the percentage the route operates on A104 corridor. From this we were able to make an initial determination as to which routes to consider for BRT services. Those with high overlap, (those with greater than 10% overlap on A104, identified on the graph as "Structural Routes"), regardless of frequency, were then evaluated further to determine if they made sense to turn into BRT services. Those with lower overlap on the A104 corridor

(identified as "Complementary Routes"), were also evaluated. The routes that had very little overlap with the A104 corridor were eliminated from consideration for BRT services.

The remaining routes were analyzed to determine if inclusion in any of the BRT service scenarios would be beneficial, from both a passenger benefit and from an operational and financial perspective (the added bus fleet outweighs the operational cost). The table below shows all the routes surveyed, the percentage overlap with the A104 corridor, and whether the route was included for consideration in any of the service scenarios.

Note that existing matatu routes that overlap with proposed BRT services were assumed to be cancelled, while those serving OD pairs not well served by the BRT services are assumed to continue down the A104 following their current route. It is standard practice to cancel parallel minibus or matatu routes when planning a new BRT system. We, therefore, did not run a scenario in which no matatu routes are cancelled although we are willing. The result would likely be a drop in demand on the BRT but it is uncertain by how much. However, this will ultimately be a political decision and the business plan for this BRT project is still under consideration.

Existing Matatu Route	Direction	Itinerary	Overlap on A104 (in km)	Overlap with A104 (in %)	Considered for any of the service scenarios	Proposed BRT route
23KAN	Outbound	Odeon-Kangemi	10.19	94%	Yes, high overlap on A104	B23
30	Inbound	Uthiru-Odeon	12.57	92%	Yes, high overlap on A104	B30
105	Outbound	Odeon-Kikuyu	19.23	90%	Yes, high overlap on A104	B105
33IMA	Inbound	Imara Daima-Commercial	11.93	86%	Yes, high overlap on A104	B33
33MK	Inbound	St Bakhita-Bus Station	11.63	85%	Yes, high overlap on A104	B33
33PM	Outbound	Commercial-Pipeline	10.62	79%	Yes, high overlap on A104	B33F
12C	Outbound	CBD-Mugoya	5.53	73%	Yes, high overlap on A104	B12
12D	Outbound	CBD-Amboseli	5.53	66%	Yes, high overlap on A104	B12
33FED	Outbound	Commercial-Posta	10.62	59%	Yes, high overlap on A104	B33F
14B	Inbound	Tmall-Bus Station	2.47	57%	No, but incorporated into new service for the service plan which includes infrastructure on Langata	B15
14A	Inbound	Strathmore-Bus Station	2.47	54%	Yes, high overlap on A104 and considered for the service plan which includes infrastructure on Langata	B14
33UTA	Inbound	Utawala-Ambassauder	11.39	43%	Yes, high overlap on A104	B33U
110KIT	Inbound	Kitengela-Railways	10.68	35%	Yes, high overlap on A104	B110B
110ATH	Outbound	CBD-Makadara	10.62	35%	Yes, high overlap on A104	B110A
48KAW	Inbound	Westlands-Kawangware	2.91	34%	Yes, high overlap on A104	B48K
48B	Inbound	Othaya-Odeon	2.67	32%	Yes, high overlap on A104	B48O
48OTH	Inbound	Othaya-Odeon	2.95	32%	Yes, high overlap on A104	B48O
11	Inbound	Hazina-CBD	1.92	26%	Yes, high overlap on A104	B11
15	Outbound	Bus Station-Langata	2.45	20%	Yes, high overlap on A104 and considered for the service plan which includes infrastructure on Langata	B15
33NGU	Inbound	Ngummo-Race course	1.01	17%	New service created	B33N
125	Inbound	Rongai-Railways	2.47	13%	Yes, high overlap on A104 and considered for the service plan which includes infrastructure on Langata	B125
24	Outbound	CBD-Karen	2.81	11%	Low demand but considered for the service plan which includes infrastructure on Langata	B24
126	Inbound	Kiserain-Railways	2.47	9%	Low demand but considered for the service plan which includes infrastructure on Langata	B125
34JKIA	Inbound	JKIA- Ambassadeur	0.22	1%	New service created	B34

Table 6: Routes considered for inclusion in BRT service scenarios.

Once this initial set of routes was defined, various combinations of services ("service scenarios") were tested. Five main service scenarios were defined based on the differing BRT Infrastructure Scenarios. That is, some services made sense to include when there was more BRT infrastructure and to exclude when there was less. Additionally, we tested two different types of BRT service patterns – direct services and trunk-feeder services. As such, we describe the various types of BRT service patterns below.

5.5.2 BRT service types

In early BRT systems, BRT services mimicked rail services: that is, one BRT service traveled on each BRT corridor. These are called **trunk-only services** since the services operate only on the trunk infrastructure. The most primitive form of trunk-only BRT systems operate services that mimic rail systems: one BRT corridor, one bus route. Mexico City's BRT was initially designed this way.

Figure 31: Mexico City's BRT system was designed with "trunk-only" services

Jakarta's BRT was also initially designed this way.
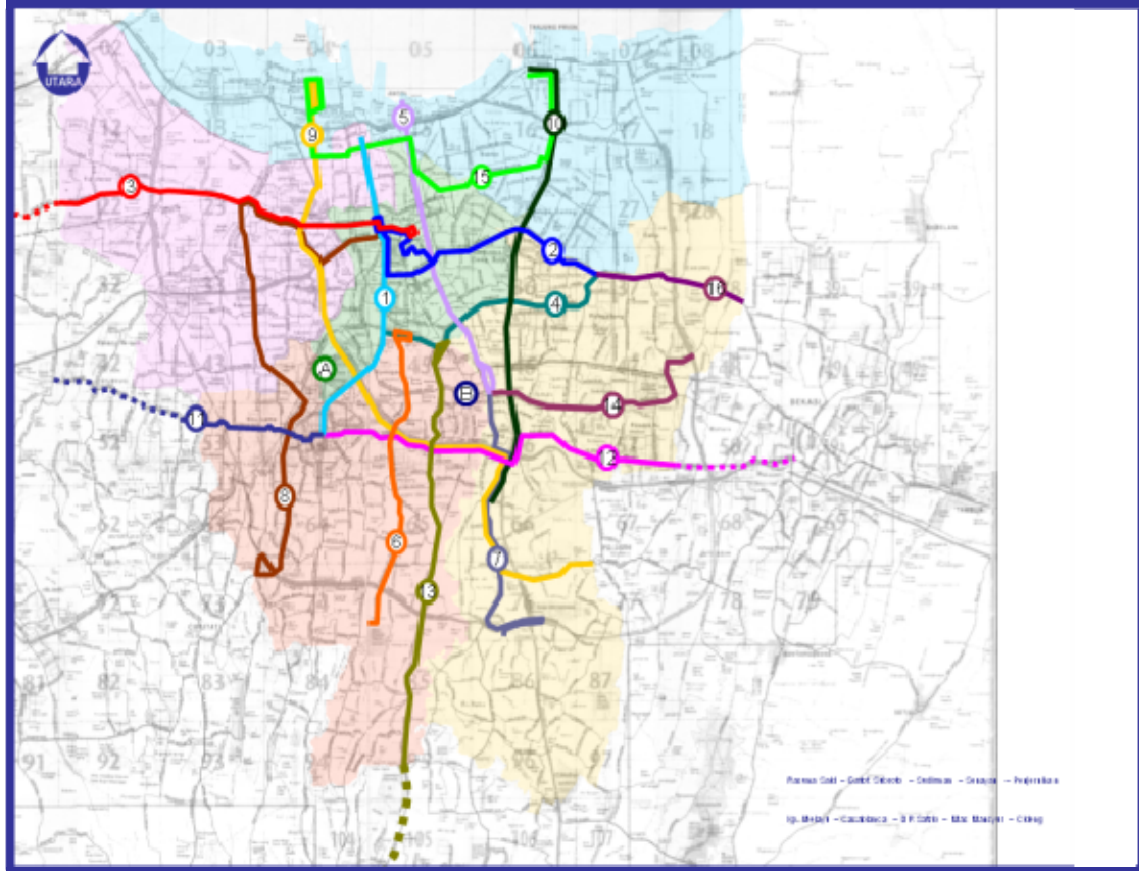
Figure 32: Jakarta's BRT was also designed with "trunk-only" services. Harmoni Station is where Lines 1, 2, and 3 intersect.

The result of designing trunk-only services without any inter-corridor routes was the need for very large transfer stations. Passengers wishing to pass from one trunk route to another had to transfer. This forced large volumes of passengers to needlessly transfer between one trunk service and another. In Jakarta, this primitive service approach required a very large amount of land for a transfer station, and even so, the station quickly became overcrowded as new corridors were added.

Figure 33: Harmoni Station transfer facility in Jakarta could have been avoided if trunk services had been continued rather than forcing a transfer between trunk-only services

Over time, some trunk-only BRT systems gradually evolved to introduce **inter-corridor services**. Inter-corridor services still travel only on the BRT infrastructure but travel between corridors so as to avoid these major transfers. Jakarta and Mexico City both finally introduced inter-corridor services to reduce severe overcrowding at transfer stations.
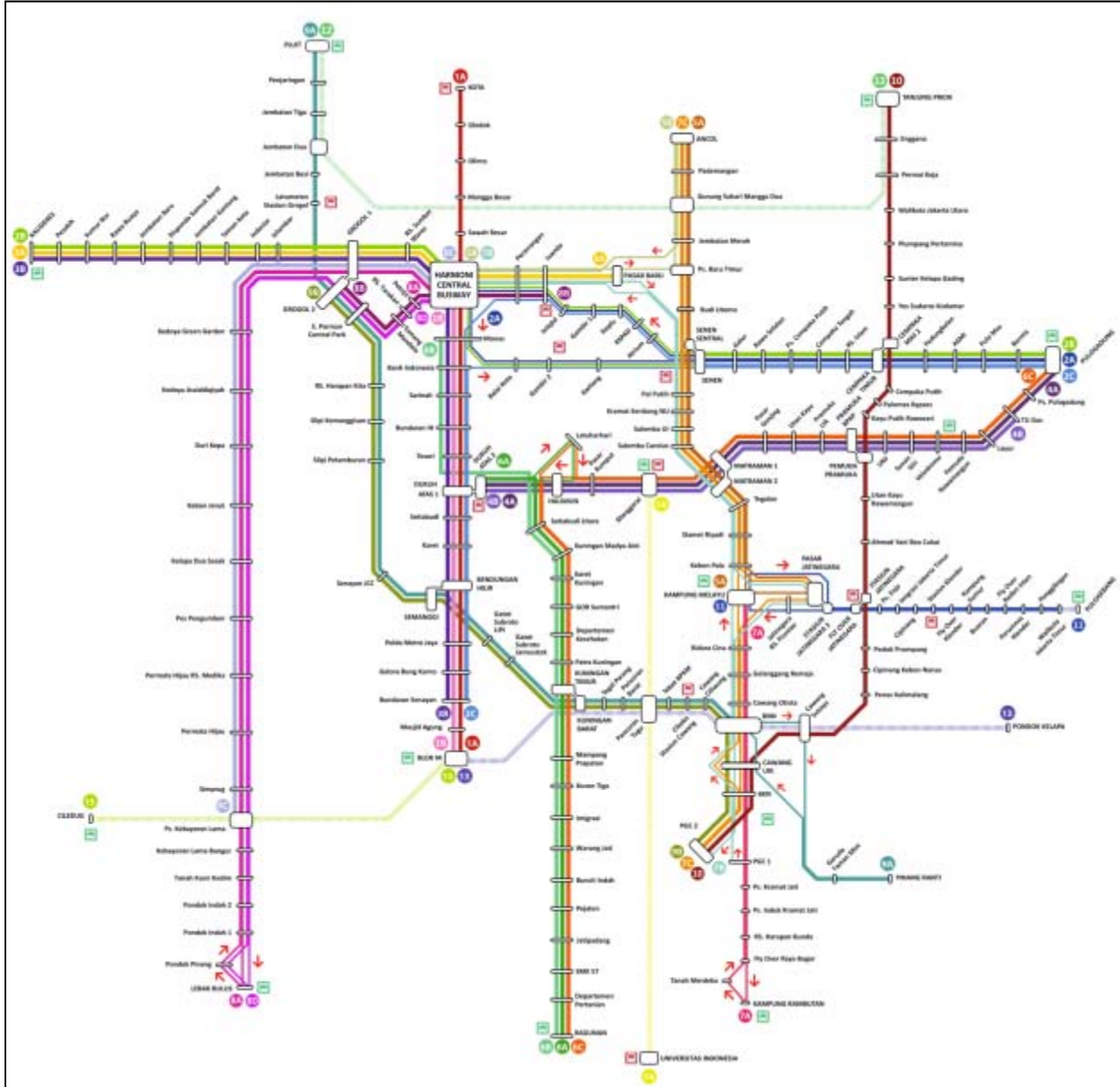
Figure 34: Jakarta added some inter-corridor services to alleviate some of the major transfer volumes occurring at stations like Harmoni Station

In addition to the design question of how to route services that operate on the trunk, there also emerged a question of how to design services that capture passengers that do not live within walking distance of a trunk corridor. Not all BRT passengers live or work directly on the trunk corridor, so in order to bring more passengers to the system, it is generally necessary to route some buses onto mixed traffic streets (direct services) or provide feeder buses.

Earlier BRT systems solved this problem by using feeder buses. In a **trunk-feeder** system, "trunk" services operate on the trunk infrastructure only (whether trunk-only or inter-corridor services) and "feeder" services

operate in mixed traffic only, bringing passengers to and from the BRT corridor. Bogota's TransMilenio was designed as a trunk-feeder system. Like with trunk-only services, trunk-feeder services require large transfer facilities because many passengers are forced to make transfers between trunk and feeder services. Additionally, many passengers choose not to use the system because of the time delay associated with this cumbersome transfer.

For years, it was believed that direct services were not compatible with full featured BRT trunk services. In the last few years, however, direct services have been successfully combined with full featured BRT on trunk routes, allowing the best of both worlds. Prior to entering dedicated BRT infrastructure, services operate in mixed traffic on local streets. The same vehicle then enters the BRT infrastructure, eliminating any need for a transfer. This requires a bus that can successfully interface with a trunk BRT station while also providing a comfortable traditional curb entrance. This is done either by having low floor buses and low platforms at trunk BRT stations, or by having BRT buses having high platform doors on one side of the bus and steps for normal curb entry.

By eliminating the need to transfer, passengers' overall trip times are reduced and they have the comfort of a one-seat ride. On the BRT corridor, services operate within the BRT infrastructure, with stops at center-aligned station platforms and doors on the right side of the buses. Off the BRT corridor, services stop along the curbside with additional doors on the left side of the buses. In addition to higher time savings and more direct routing, direct services also reduce infrastructure costs and land consumption due to a reduction in the need for large transfer facilities.

Guangzhou, China was the first BRT system to have a fully direct services model that also had full featured BRT trunk infrastructure.
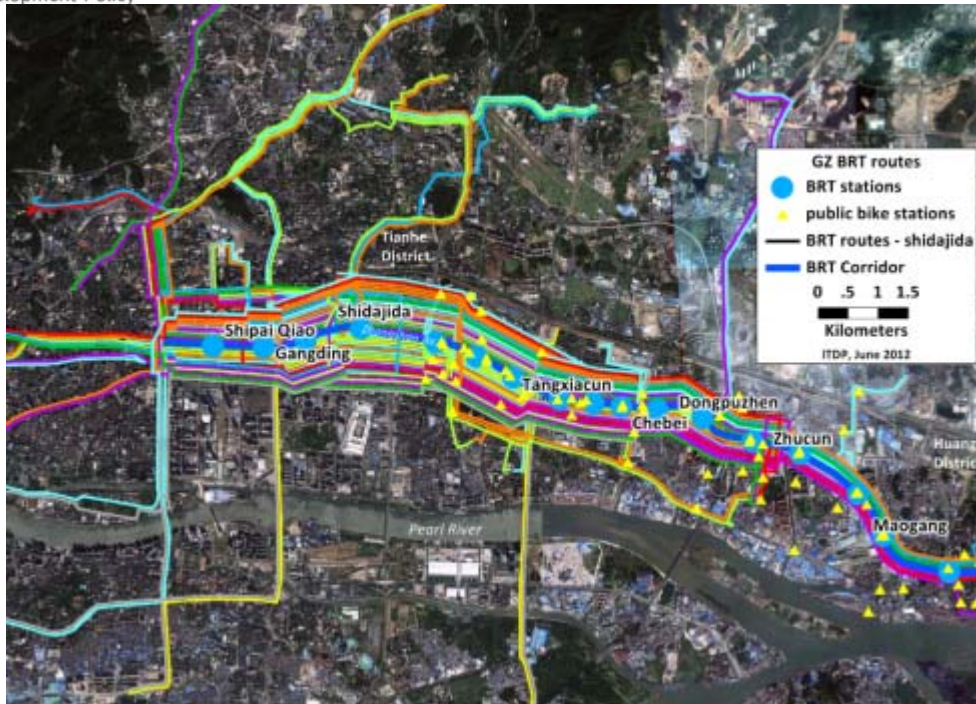
Figure 35: Guangzhou's fully direct services BRT system includes services that operate both on- and off-corridor

Around the same time, Johannesburg, South Africa also implemented some direct services on the Rea Vaya BRT (known in Johannesburg as "complementary" services). In fact, Johannesburg implemented a hybrid system of trunk-feeder and direct services.
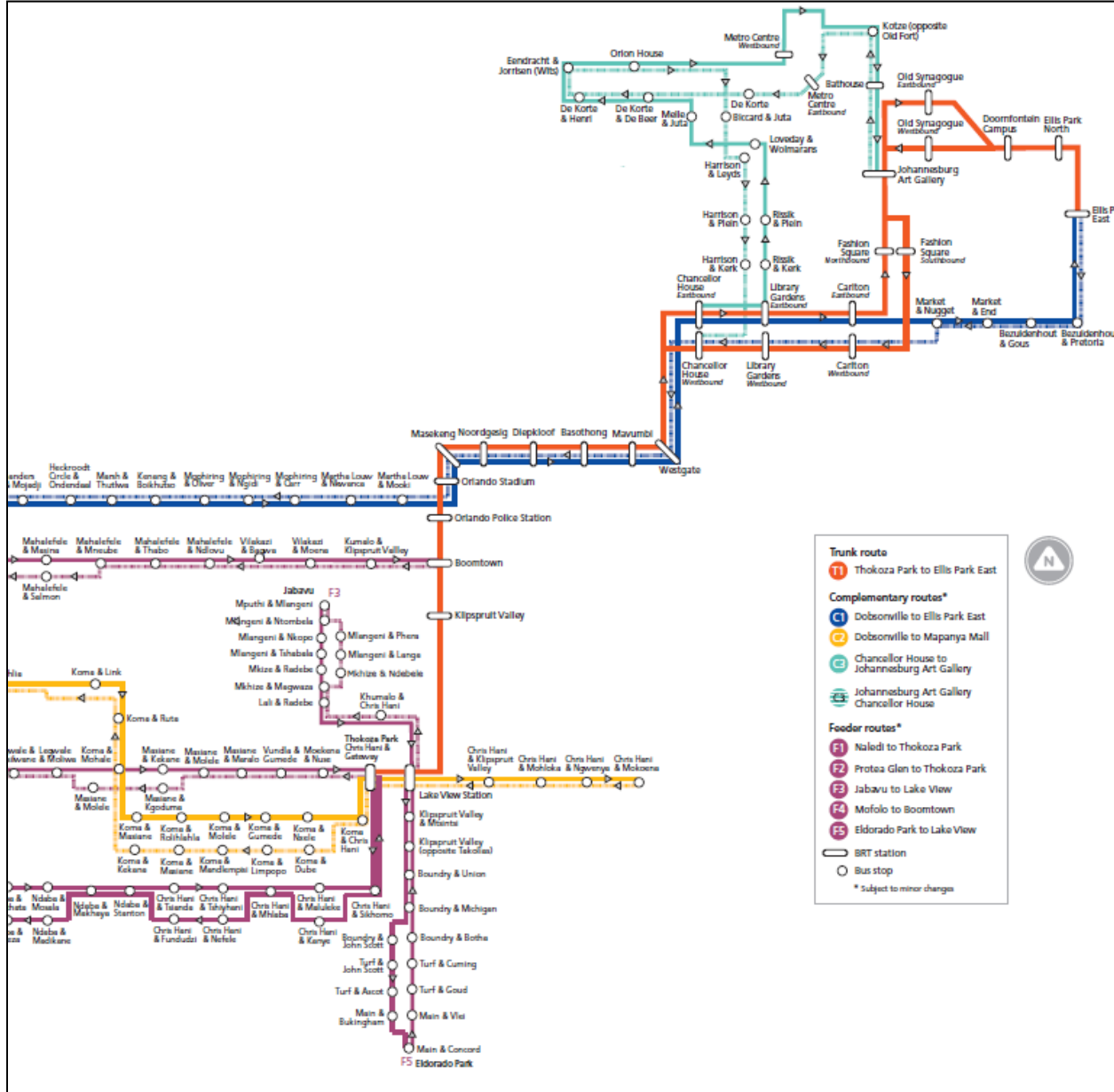
Figure 36: Johannesburg implemented a hybrid system of direct services and trunk-feeder services

Because direct services tend to attract more passengers, due providing a one-seat ride, because direct services tend to need less fleet, and because direct services avoid transfer terminal delay and indirectness of route delay, and as they also avoid the need for a large and expensive transfer facility, we generally prefer to test direct services.

The MRTS Harmonisation Study assumed a trunk-only service with no inter-corridor routes: the most basic form of BRT services. As the study never made clear whether there were to be no feeder services or whether

the service was assumed to have feeder routes yet to be specified, ITDP created two service scenarios (Scenarios I & III) which split our proposed direct services into trunk-feeder services.

5.5.3   Scenario I: Trunk-Feeder on KeNHA Infrastructure (Infrastructure Scenario 1)

Scenario I is a set of trunk-feeder services that operate on A104 under the current KeNHA infrastructure plan (Infrastructure Scenario 1). This is a more detailed service plan scenario that is consistent with what was proposed in the Harmonisation Study. It provides for trunk services that operate between City Cabanas and James Gichuru with one local and one express service. As the infrastructure on the A104 has passing lanes, we added a trunk express service as it did not appear to be precluded by the Harmonisation Study proposals, and it had significant time savings advantages. Transfer terminals would be required at both ends (i.e., City Cabanas and James Gichuru) as well as near the CBD. From there, we added several feeder services that were not detailed but not precluded by the Harmonisation Study proposal. These feed passengers into the trunk terminals from multiple popular destinations.
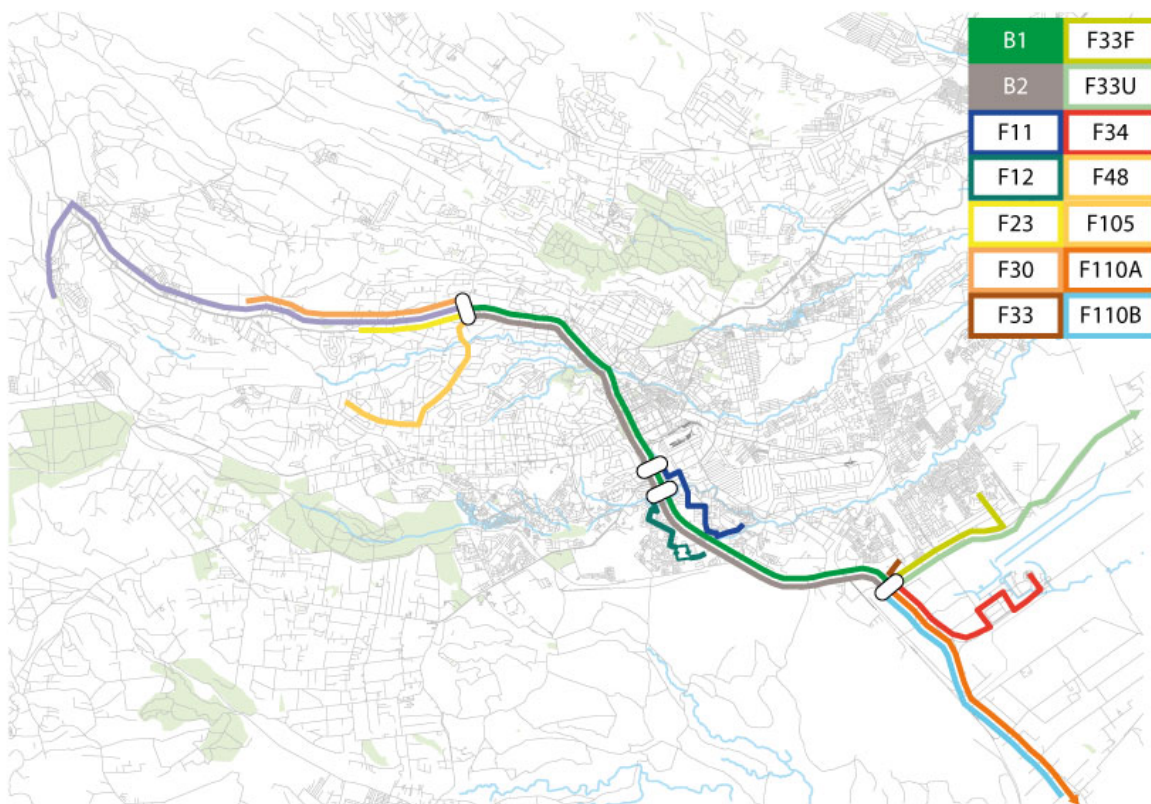
Figure 37: BRT Service Scenario I: Trunk-Feeder on KeNHA Infrastructure

Additionally, while this scenario includes feeder services at the four terminals, because the service plan for the longer term MRTS network, as found in the MRTS Harmonisation Study, precludes the inclusion of inter-corridor routes, three additional transfer stations would need to be built where the BRT Ndovu Service (A104)

crosses the proposed BRT Simba Service at Langata Road, where these two services cross the Chui Line (Red) at Haile Selassie, and where these two services cross the Nyati (Green) Line at Kenyatta. In addition, an exclusive BRT turning movement would need to be provided the intersection of the A104 and University Way.
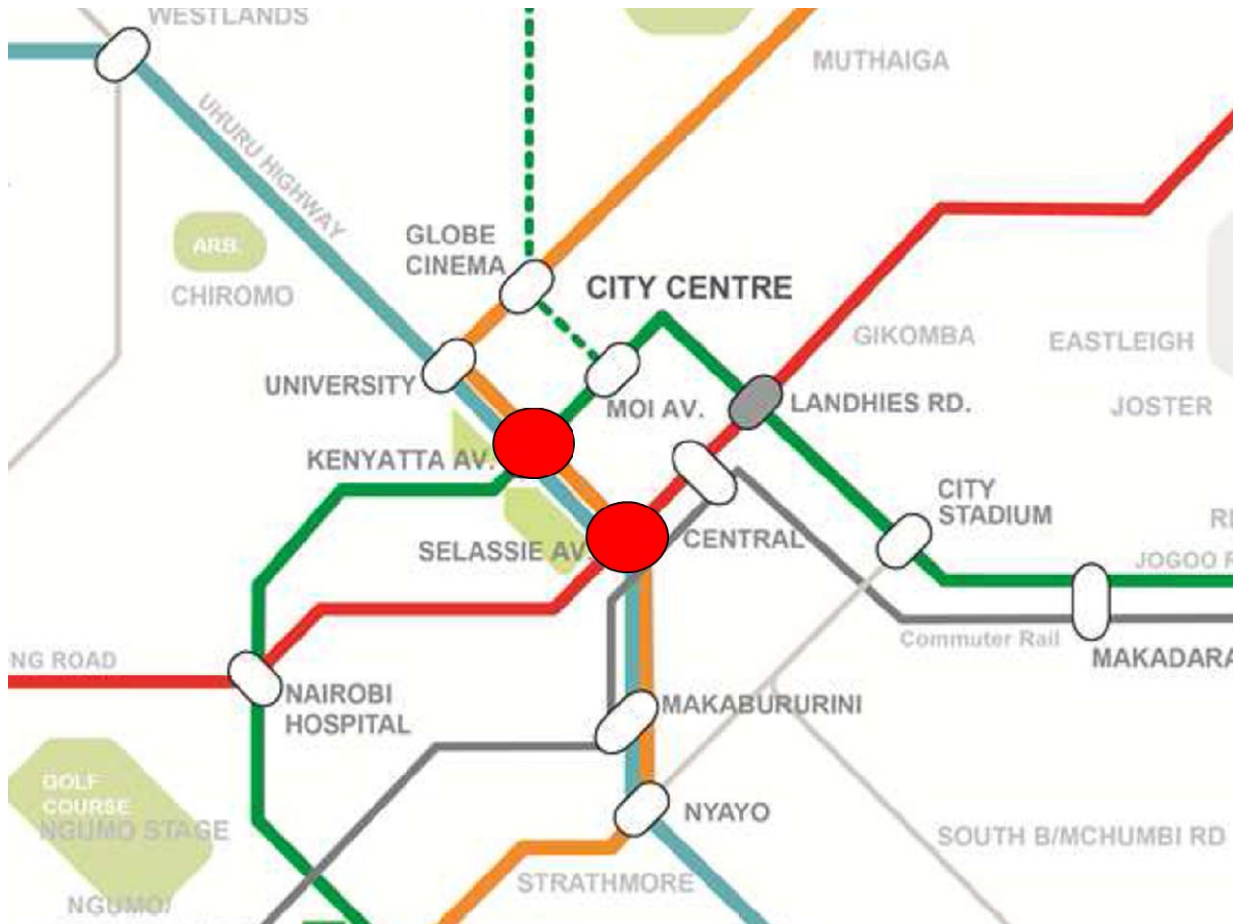
Figure 38: Under Scenario I, two major transfer facilities will be required in order to facilitate transfers to future BRT corridors

Running this scenario through the model yielded the following results:

DATA MODEL			MODEL RESULTS								
Route	Veh type	Length (km)	Run time (min)	Boarding	Pax km	Pax hours	Max volume	Max load	Freq	Hdwy (min)	Fleet
T1	Artic	32.7	84.03	13 602	68 516	2 921	3 834	2.00	24.0	2.5	34
T2	Artic	32.7	66.03	13 802	92 119	3 097	5 318	1.66	33.2	1.8	37
TOTAL		65	150	27 404	160 635	6 017					71

DATA MODEL			MODEL RESULTS								
Route	Veh type	Length (km)	Run time (min)	Boarding	Pax km	Pax hours	Max volume	Max load	Freq	Hdwy (min)	Fleet
F105	Std	29.8	126.7	7 254	74 773	5 223	4 348	4.03	48.3	1.2	102
F11	Std	9.5	53.9	1 562	4 385	445	950	0.88	10.6	5.7	10
F110A	Std	39.2	115.9	1 687	23 559	924	967	0.90	10.7	5.6	21
F110B	Std	18.4	54.8	1 033	7 544	310	650	0.60	7.2	8.3	7
F12	Std	9.3	71.8	130	249	32	76	0.07	4.0	15.0	5
F23	Std	6.9	18.6	3 111	10 645	528	2 481	2.30	27.6	2.2	9
F30	Std	14.6	50.9	2 140	9 706	595	1 227	1.14	13.6	4.4	12
F33	Std	2.3	5.9	2 354	2 636	182	1 716	1.59	19.1	3.1	2
F33F	Std	12.1	83.9	1 107	3 490	389	568	0.53	6.3	9.5	9
F33U	Std	27.0	165.2	1 406	11 721	1 067	813	0.75	9.0	6.6	25
F34	Std	15.2	54.0	76	228	17	76	0.07	4.0	15.0	4
F48	Std	13.0	105.3	760	2 752	387	339	0.31	3.8	15.9	7
TOTAL		197	907	22 620	151 689	10 098					213

Table 7: Results of Scenario I

This scenario requires 284 buses in total, 71 articulated (18 meter) and 213 standard (12 meter). The scenario is expected to attract approximately 305,000 passengers per day, and 33,877 passengers during the peak hour. Some 63% of the total trips are forced to transfer from a feeder route onto the trunk service. (27,404 + 22,620= 50,024 * 0.63 = 33,877). Daily demand is composed of 58,257 trips boarding a feeder bus and getting off the feeder before it reaches the trunk service, another 154,322 daily trips that board feeders and transfer onto the trunk service, and another 92,313 daily trips that are boarding directly onto a trunk service.

5.5.4 Scenario II: Direct services on KeNHA Infrastructure (Infrastructure Scenario 1)

Scenario II proposes a set of direct services that would operate on the A104 on the current KeNHA infrastructure plan (Infrastructure Scenario 1) but would travel through the CBD where passenger demand is high. That is, services operate along trunk BRT infrastructure between City Cabanas and James Gichuru and continue beyond to multiple destinations, without a forced transfer. The routes are generally the same in this scenario as in Scenario I except rather than cutting the routes at four terminals and continuing them as feeders, the routes are simply continuous. This scenario does not require transfer facilities. This scenario also varies from Scenario I in that the routes travel through the CBD. In Scenario I, this would not have made sense as we would have needed to create feeder routes for just the CBD portion of the service plan. These feeder routes would have been extremely short and stuck in traffic for their entire routes. Hence, we only began routing services through the CBD in this scenario.
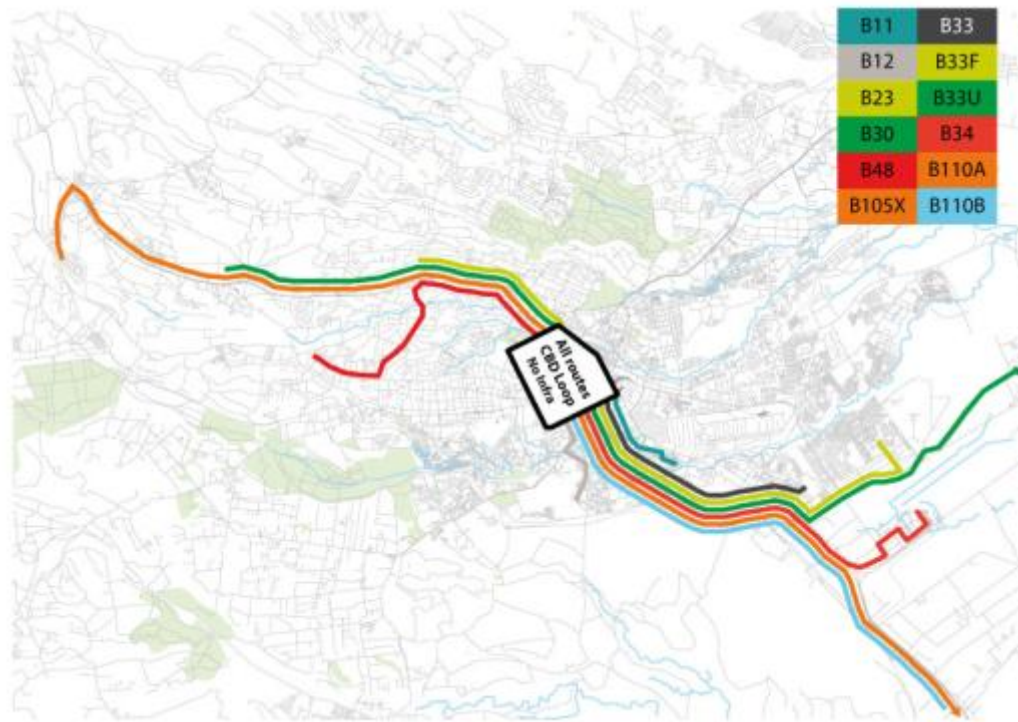
Figure 39: BRT Service Scenario II: Direct services on KeNHA Infrastructure

Running this scenario through the model yielded the following results:

DATA MODEL			MODEL RESULTS								
Route	Veh type	Length (km)	Run time (min)	Boarding	Pax km	Pax hours	Max volume	Max load	Freq	Hdwy (min)	Fleet
B105X	Artic	44.9	183.73	8 495	112 243	7 489	4 568	1.43	28.6	2.1	88
B11	Std	15.5	82.76	2 055	6 811	647	1 024	0.57	11.4	5.3	16
B110A	Std	62.4	184.39	2 047	35 766	1 520	973	0.54	10.8	5.5	34
B110B	Std	41.7	126.30	1 466	16 667	758	690	0.38	7.7	7.8	17
B12	Std	16.5	96.29	1 212	4 386	347	637	0.35	7.1	8.5	12
B23	Artic	22.0	82.75	6 188	44 143	2 952	3 252	1.02	20.3	3.0	29
B30	Artic	29.7	110.56	3 363	23 758	1 546	1 500	0.47	9.4	6.4	18
B33	Artic	24.0	73.11	5 655	46 305	2 240	2 997	0.94	18.7	3.2	23
B33F	Artic	35.3	155.33	2 899	27 868	1 750	1 064	0.33	6.7	9.0	18
B33U	Std	50.3	247.68	2 965	18 738	1 473	676	0.38	7.5	8.0	32
B34	Artic	38.4	124.48	3 245	36 387	1 850	1 745	0.55	10.9	5.5	23
B48	Artic	28.2	161.43	3 872	34 738	3 095	2 490	0.78	15.6	3.9	42
TOTAL		409	1629	43 462	407 810	25 666					352

Table 8: Results of Scenario II

This scenario requires 352 buses in total, 241 articulated (18 meter) and 111 standard (12 meter). The scenario is expected to attract approximately 391,158 passengers per day and 43,462 passengers during the peak hour. This scenario has 86,000 more daily passengers than the trunk-feeder scenario, and each bus carries 1,111 daily passengers, compared to the trunk feeder scenario where each bus only caries 1,074 daily passengers. In

other words, in an apples-to-apples comparison, the direct service scenario attracts more passengers and requires less fleet per passenger than the trunk-feeder scenario on the same infrastructure. However, the lack of BRT infrastructure in the CBD slows down these services dramatically as compared to the following three scenarios.

5.5.5   Scenario III: Trunk-Feeder on KeNHA Infrastructure + CBD (Infrastructure Scenario 3)

For Scenario III, full BRT infrastructure in a loop around the CBD was assumed. Based on previous work, discussed in detail in the "Nairobi BRT Phase I Infrastructure & Intersection Recommendations Detailed Report," the best loop for BRT infrastructure is Haile Selassie Avenue, Moi Avenue, and University Way. Scenario III assumes that trunk service operate inside this CBD loop. Feeder services were included in this scenario in a manner similar to those in Scenario I: trunk routes were severed at the two terminals (City Cabanas and James Gichuru) and several feeder services took passengers in multiple directions from there. Two transfer terminals are required in this scenario.
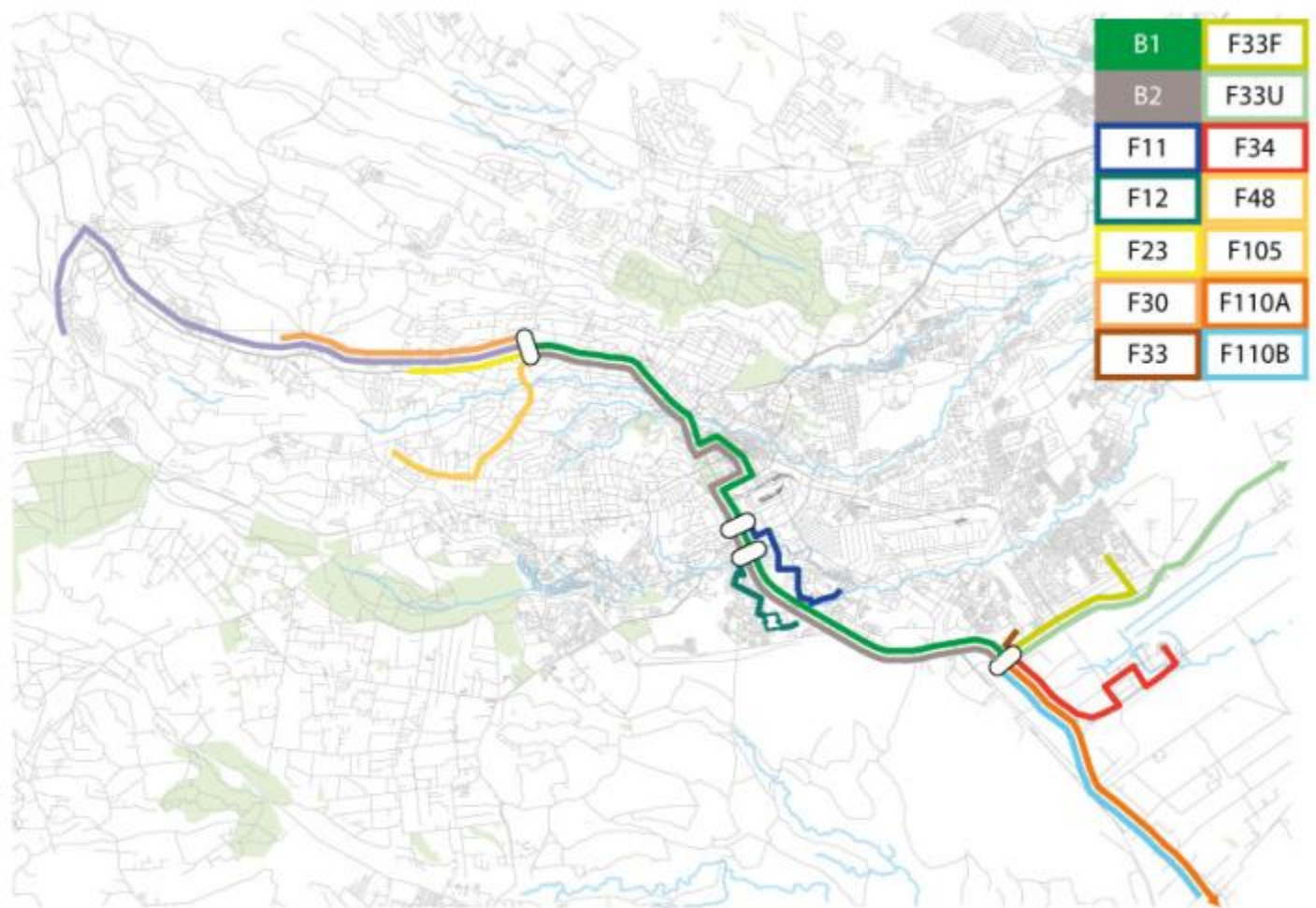

Figure 40: BRT Service Scenario III: Trunk-feeder on KeNHA Infrastructure + CBD

Additionally, as with Scenario I, several additional transfer facilities would be required in and around the CBD in order to facilitate the transfer between the Ndovu Corridor and future BRT corridors.

In Scenario III, we did not include the matatu routes that currently come in from Langata Road. This is because Langata Road is too congested to provide a reliable BRT feeder service. We considered as an alternative, including full BRT infrastructure on Langata Road in this scenario so that feeder services could bypass this congestion. However, Langata Road is so close to the CBD and the time penalty to passengers coming from Langata Road imposed by a transfer to the trunk route for such a short distance is too great and cannot be justified by providing a feeder service. Instead, the matatu routes which currently use Langata Road and turn onto A104 will continue as they currently are today. This will reduce the number of passengers using the BRT and will mean more matatus on A104 in the segment between Langata Road and the CBD. For a similar reason, Routes B11 & B12, which also turn off of A104 at a distance near the CBD, were eliminated as well.

Scenario III loses passengers to non-BRT routes because of the transfer required. For example, passengers who are going to the airport from the CBD will travel south on either routes B34, B33U, B33F but will have to make a transfer to a feeder route (F34) to complete their trip. Alternatively, matatu route 34JKIA circumvents this by travelling from the CBD along Jogoo Road and does not require passengers to transfer. Despite the faster speeds on the BRT, the 34JKIA is still a shorter trip and doesn't require a transfer.

DATA MODEL			MODEL RESULTS								
Route	Veh type	Length (km)	Run time (min)	Boarding	Pax km	Pax hours	Max volume	Max load	Freq	Hdwy (min)	Fleet
B1	Artic	35.6	91.01	21 123	112 358	4 797	6 375	1.99	39.8	1.5	61
B2	Artic	35.6	73.01	12 296	95 191	3 229	4 157	1.52	26.0	2.3	32
TOTAL		71	164	33 419	207 549	8 026					93

DATA MODEL			MODEL RESULTS								
Route	Veh type	Length (km)	Run time (min)	Boarding	Pax km	Pax hours	Max volume	Max load	Freq	Hdwy (min)	Fleet
F105	Std	29.8	126.7	7 254	74 773	5 223	4 348	4.03	48.3	1.2	102
F11	Std	9.5	53.9	1 568	4 535	467	950	0.35	10.6	5.7	10
F110A	Std	39.2	115.9	1 687	23 559	924	967	1.07	10.7	5.6	21
F110B	Std	18.4	54.8	1 033	7 544	310	650	0.60	7.2	8.3	7
F12	Std	9.3	71.8	114	217	29	54	0.02	4.0	15.0	5
F23	Std	6.9	18.6	3 111	10 645	528	2 481	0.92	27.6	2.2	9
F30	Std	14.6	50.9	2 140	9 706	595	1 227	0.45	13.6	4.4	12
F33	Std	2.3	5.9	2 354	2 636	182	1 716	0.64	19.1	3.1	2
F33F	Std	12.1	83.9	1 376	4 393	487	714	0.53	7.9	7.6	12
F33U	Std	27.0	165.2	1 544	11 939	1 096	937	0.69	10.4	5.8	29
F34	Std	15.2	54.0	121	479	34	121	0.04	1.3	44.6	2
F48	Std	13.0	105.3	2 366	12 203	1 619	1 966	2.91	21.8	2.7	39
TOTAL		197	907	24 668	162 628	11 493					250

Table 9: Results of Scenario III

This scenario resulted in 32,574 AM peak hour passengers and 297,000 daily passengers. A fleet of 343 buses, with 93 articulated buses and 250 standard buses is required.

5.5.6 Scenario IV: Direct services on KeNHA Infrastructure + CBD (Infrastructure Scenario 3)

This scenario is similar to the Scenario III but includes direct services rather than trunk-feeder services. Again, as in Scenario III, BRT services that turn onto the corridor from Langata Road were not included. The lack of BRT infrastructure on Langata Road would too drastically affect the operation of BRT services on Langata. This scenario, therefore, performs better, in terms of overall trip time, if those services are not included in the BRT service plan and kept as matatu routes. There are 12 BRT routes in this scenario.
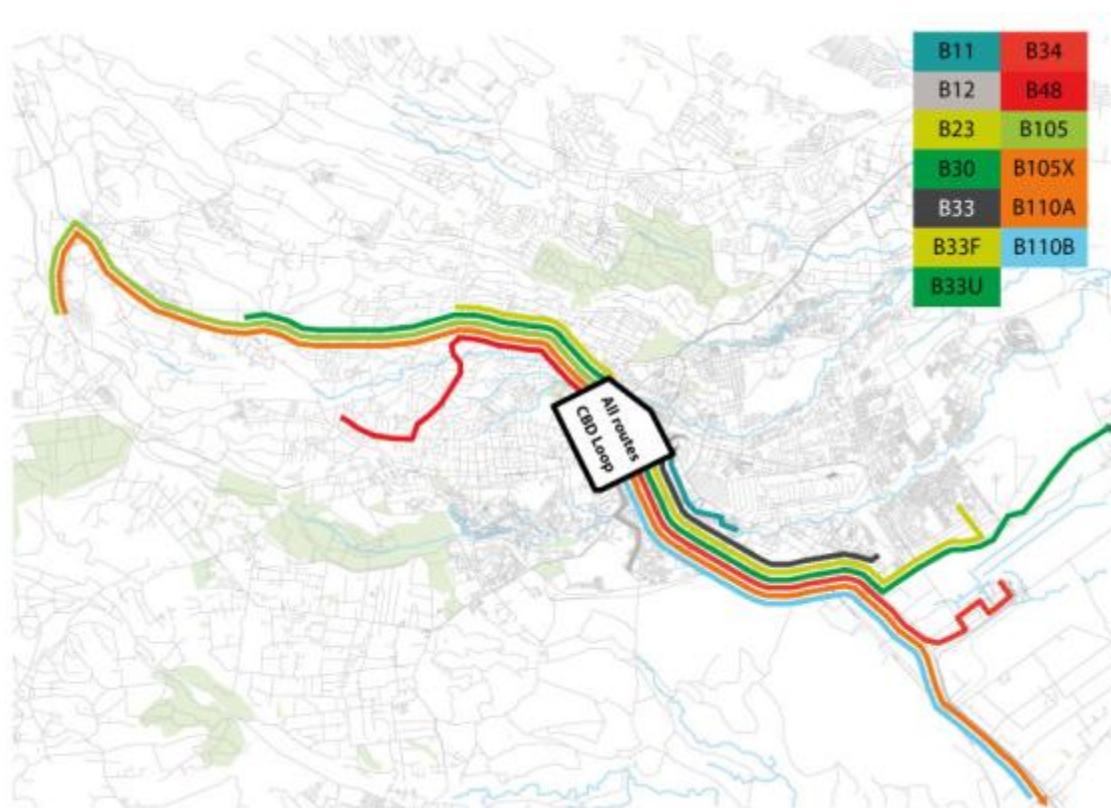

Figure 41: BRT Service Scenario IV: Direct services on KeNHA Infrastructure + CBD

Because this is a direct services scenario, transfer terminals are not required, either today or for connection with future BRT corridors.

DATA MODEL			MODEL RESULTS								
Route	Veh type	Length (km)	Run time (min)	Boarding	Pax km	Pax hours	Max volume	Max load	Freq	Hdwy (min)	Fleet
B105X	Artic	43.2	161.96	9 882	112 985	6 671	4 153	0.87	26.0	2.3	71
B11	Std	14.6	67.49	1 948	6 421	552	986	0.37	11.0	5.5	13
B110A	Artic	61.5	168.62	4 224	58 074	2 114	1 811	0.38	11.3	5.3	32
B110B	Std	41.7	113.61	1 423	10 969	445	517	0.19	5.7	10.4	11
B12	Std	16.5	84.10	870	1 934	147	289	0.11	3.2	18.7	5
B23	Artic	21.3	47.58	3 539	30 080	1 155	2 581	0.54	16.1	3.7	13
B30	Artic	32.1	77.48	4 120	29 743	1 093	2 539	0.53	15.9	3.8	21
B33	Artic	23.1	57.83	5 552	44 159	1 811	2 834	0.59	17.7	3.4	18
B33F	Std	35.4	143.13	3 293	27 637	1 524	1 367	0.51	15.2	4.0	37
B33U	Std	49.4	232.41	3 528	20 737	1 497	786	0.29	8.7	6.9	34
B34	Std	38.4	112.28	3 178	28 896	1 256	1 356	0.50	15.1	4.0	29
B48	Artic	28.1	143.53	4 769	44 813	3 652	3 388	0.71	21.2	2.8	51
TOTAL		405	1410	46 326	416 448	21 916					335

Table 10: Results of Scenario IV

The total number of AM peak hour passengers in this scenario is approximately 41,000 and the total number of daily passengers is approximately 369,000 passengers per day. This scenario requires a fleet of 335 buses, with 206 articulated and 129 standard size.

5.5.7 Scenario V: Direct services on KeNHA Infrastructure + CBD + Langata (Infrastructure Scenario 4)

In this scenario, those services which mimic the itineraries of the highest-demand existing matatu routes were all included. Since much of the passenger demand goes directly into the CBD, most of the routes in this service plan enter the CBD. Due to particularly high congestion in the CBD, and the fact that operating these routes in CBD traffic would mean long delays for the BRT system as a whole, this scenario assumes that full BRT infrastructure will be built in the CBD to accommodate these services. Some of these routes come from other parts of the city, operate in mixed traffic for a part of their route, then join the BRT infrastructure along the A104 before turning into the CBD. For the most part, the congestion on these other roads is not so bad that the system would be unviable.

However, in this scenario, unlike in the others, BRT services that turn onto the corridor from Langata Road were included. But congestion on the first 1.5 km is so bad that these services would not be viable if left in mixed traffic. Thus, Scenario V also includes full BRT infrastructure for this first 1.5 kilometers of Langata Road (Infrastructure Scenario 4).

Regarding which matatu routes were included, some were included as is and transformed into BRT routes, while others were simplified or combined with others. The total number of BRT services included in this scenario is 16. This also includes some local and express versions of the same service.
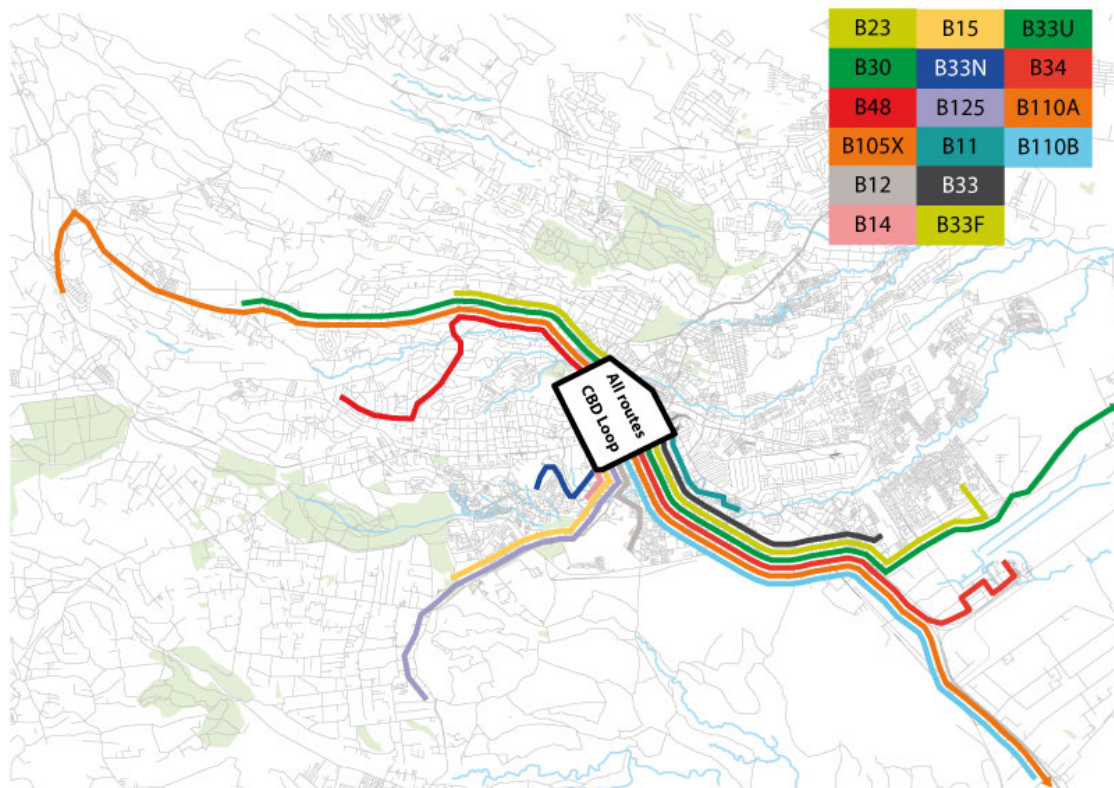
Figure 42: BRT service scenario V: Direct services on KeNHA Infrastructure + CBD + Langata

The following table details the modeling results, by BRT route, in the AM peak hour:

DATA MODEL			MODEL RESULTS								
Route	Veh type	Length (km)	Run time (min)	Boarding	Pax km	Pax hours	Max volume	Max load	Freq	Hdwy (min)	Fleet
B105X	Artic	44.9	162.34	7 599	101 573	6 276	3 846	1.20	24.0	2.5	66
B11	Std	15.5	67.08	1 996	6 732	576	1 024	0.57	11.4	5.3	13
B110A	Std	62.4	168.21	2 338	37 183	1 427	973	0.54	10.8	5.5	31
B110B	Std	41.7	108.12	1 575	18 440	713	906	0.50	10.1	6.0	19
B12	Std	16.5	80.61	1 136	4 255	241	592	0.33	6.6	9.1	9
B125	Artic	28.5	154.39	3 284	22 645	2 395	1 789	0.56	11.2	5.4	29
B14	Std	10.5	35.70	1 152	3 501	210	909	0.51	10.1	5.9	7
B15	Artic	25.1	137.44	3 615	17 833	1 675	1 211	0.38	7.6	7.9	18
B23	Artic	22.0	62.36	5 672	37 227	1 859	2 980	0.93	18.6	3.2	20
B30	Artic	29.6	89.16	6 142	39 934	1 960	2 707	0.85	16.9	3.5	26
B33	Artic	24.0	56.42	5 336	44 092	1 801	2 888	0.90	18.1	3.3	17
B33F	Artic	35.4	139.64	3 148	29 658	1 505	1 343	0.42	8.4	7.1	20
B33N	Artic	15.9	56.90	2 378	13 086	866	2 063	0.64	12.9	4.7	13
B33U	Std	50.3	232.00	3 620	20 678	1 569	929	0.52	10.3	5.8	40
B34	Artic	38.4	108.79	3 480	38 189	1 579	1 643	0.51	10.3	5.8	19
B48	Artic	28.1	140.04	4 071	35 198	2 768	2 540	0.79	15.9	3.8	38
TOTAL		489	1799	56 542	470 225	27 420					385

Table 11: Results of Scenario V

The total number of AM peak hour passengers who will use the BRT in this scenario is approximately 49,887, which translates to approximately 450,000 daily passengers. This will require a total fleet of 385 buses: 266 articulated 18-meter buses and 119 standard 12-meter buses.

It is important to reiterate that the results of this scenario are dependent on the completion of full BRT infrastructure on University Way, Haile Selassie Avenue, and Moi Avenue in the Nairobi CBD and on the first 1.5 kilometers of Langata Road. Further, the fully dedicated BRT-only turns that we recommended in the "Nairobi BRT Phase I Infrastructure & Intersections" report (Riverside Drive, University Way, Haile Selassie Avenue, Langata Road, Popo Road, Enterprise Road, and Airport North Road) remain critical to accommodating these services and ensuring that the system does not break down. If any of these elements of BRT infrastructure are excluded from the Ndovu Corridor, a majority of the benefits of the project are lost.

The below figure shows the change in all public transport passenger volumes on the BRT corridor and on nearby streets for this scenario. The green indicates a gain in passengers and the red indicates a loss in passengers. Not surprisingly, the most new passengers are gained on the A104 itself. This is due to several routes being pulled onto the BRT infrastructure. Trips previously made on the B48, B33N, and B34 matatu routes, which traveled on Jogoo Road, Enterprise Road, Mbagathi Way, and Ngong Road, have also shifted to other streets, mainly onto the BRT on A104.

5.6 Comparison of scenarios

A BRT System should be designed to serve as many passengers as possible. Indeed, the MRTS Harmonisation Study defined the aim of the MRTS as being, "…*to realise a public transport system with a capacity as high as possible and with a high degree of independence from other traffic.*" We therefore, begin comparison of the five scenarios by looking at daily BRT passengers.
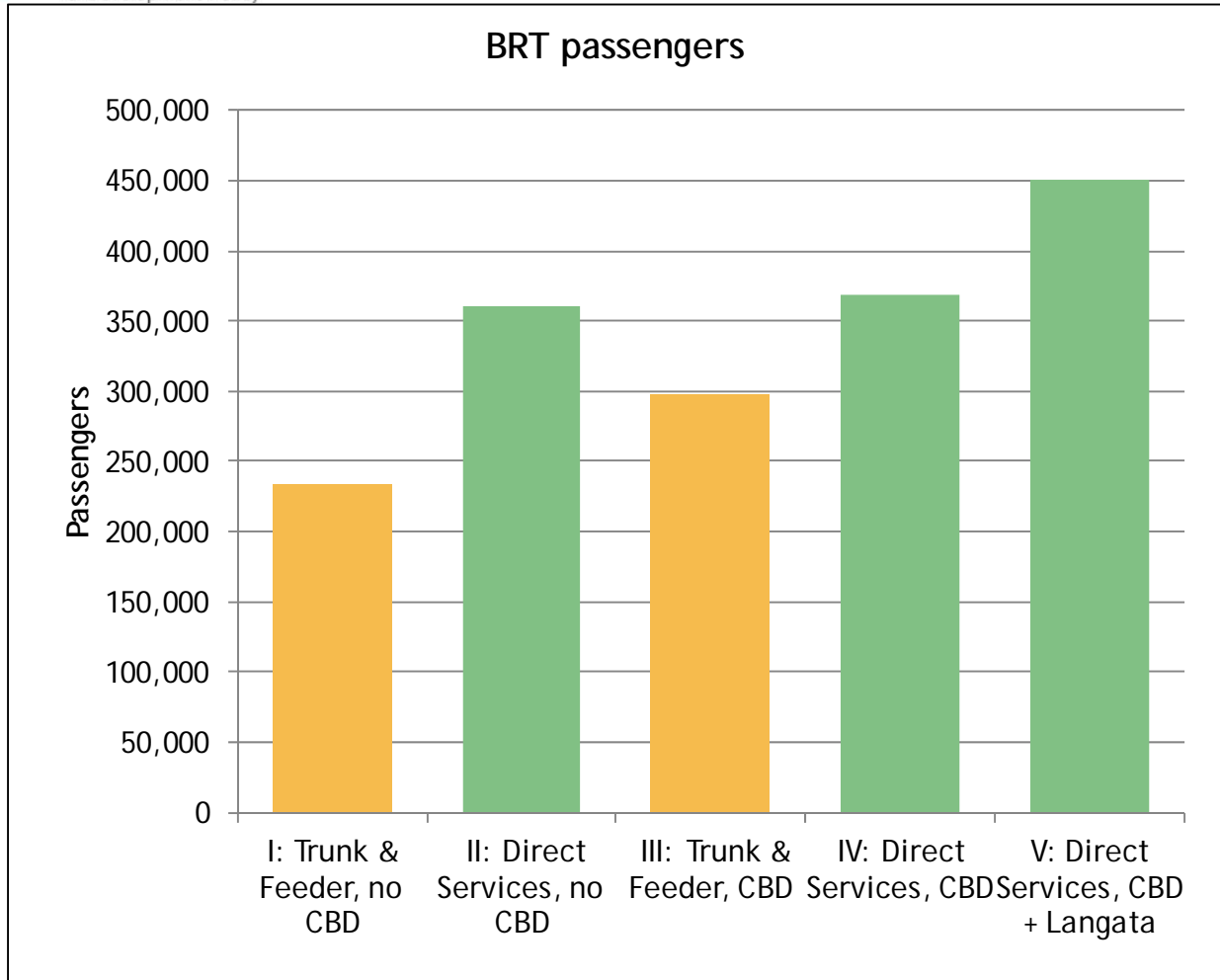
Figure 43: Comparison of daily BRT passengers across the five scenarios

From this chart, we can see that the direct services scenarios attract more passengers than the trunk-feeder scenarios. This is logical since it is more attractive for a passenger to ride a mass transit system if he/she does not have to make a transfer. We also see that by adding CBD infrastructure and services, ridership also increases. Finally, by adding BRT infrastructure and services on the first 1.5 kilometers of Langata Road, we reach a ridership of 450,000 per day. **From a ridership perspective, Scenario V performs the best**.

Note that Scenarios II and IV attract similar numbers of passengers. That is because both scenarios are direct service scenarios which go through the CBD. However, as we will see in Figures 45 and 46 below, Scenario IV creates a much greater time savings per passenger due to the BRT infrastructure which is assumed in Scenario IV to go through the CBD.

No matter what the scenario, some number of passengers will remain on matatus. First, this is because some of the matatu routes we surveyed are not be included in any of the five scenarios as BRT routes. For example, we surveyed several routes on Jogoo Road which are not included under any of the scenarios. Second, there

are some matatu routes which do not directly compete with the BRT system but which have the ability to take passengers from their origin to their destination via an alternate path, either with a one-seat ride or with a transfer. In some of the scenarios, it is still faster to take a matatu via an alternate path, even with traffic congestion than to take the BRT which requires a transfer and may not go directly into the CBD. The chart below shows what percentage of passengers will remain on the surveyed matatus under each of the five scenarios, as well as the baseline.
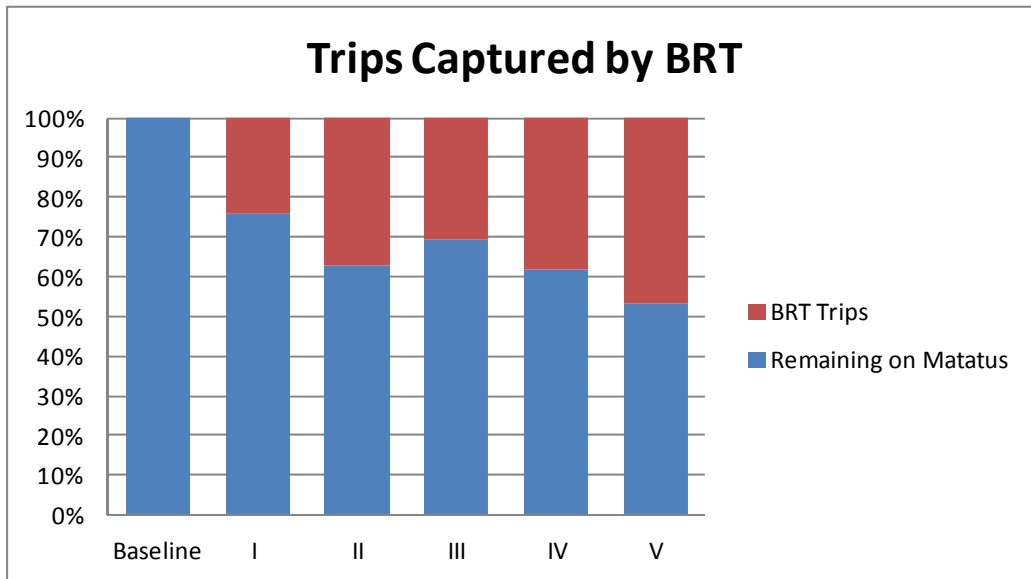

Figure 44: Comparison of passenger volumes transferring off of surveyed matatu routes and onto the BRT under each scenario

As with the previous chart which showed only ridership, this chart shows that more riders will shift out of their matatus under Scenario V. As a result, fewer matatus will be on the streets, providing some alleviation for the high levels of traffic congestion in Nairobi.

We also looked at how much time each passenger saves by using the BRT. The chart below shows time saved per passenger in minutes but it must be kept in mind that these values are averaged out across all public transport passengers – matatu and BRT – for all routes surveyed. That is, it includes passengers who remain on matatus.
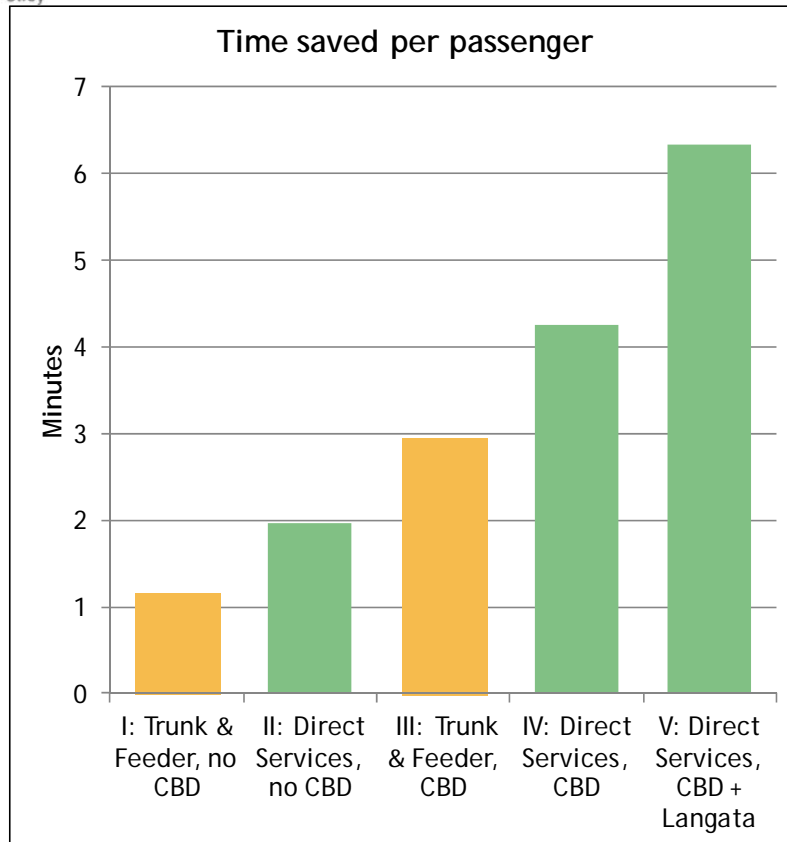
Figure 45: Average time (in minutes) saved by all public transport passengers under each scenario

If just the benefits to the BRT passengers are considered, the time savings for Scenario V remains better than the other scenarios, and looks much more significant as a share of the total trip time.
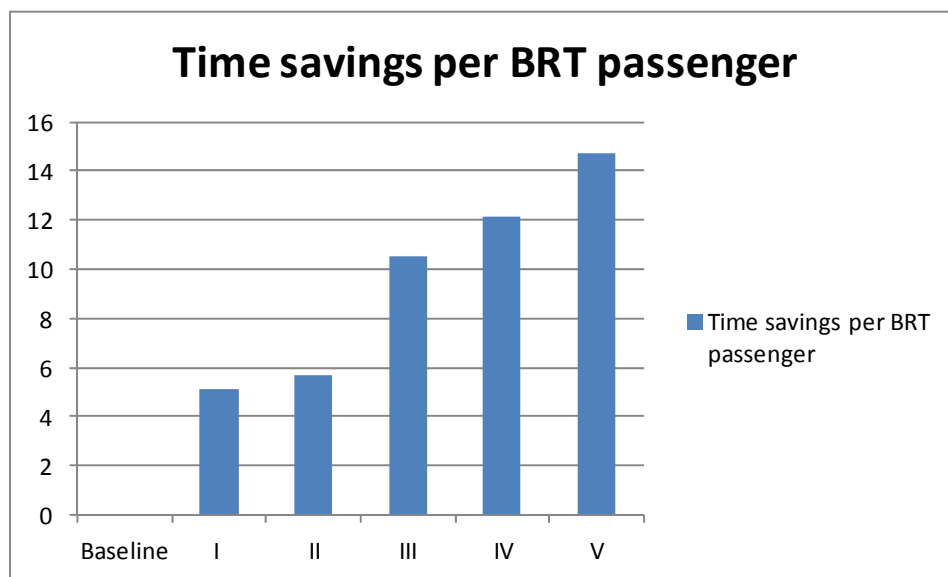

Figure 46: Average time (minutes) saved by BRT passengers

Based on ridership and overall passenger time savings, the best-performing scenario is Scenario V. That is, the Phase I BRT corridor on the A104 highway would best serve its users if it offered direct services rather than trunk-feeder services and provided these services on fully dedicated BRT infrastructure through the CBD and on Langata Road.

This scenario captures most of the existing passengers using the corridor today and offers them a convenient "one-seat ride." This direct services scenario also captures more of the existing public transport demand inside the BRT system by incorporating as many matatu routes into the system as possible, thereby maximizing the utilization of the BRT lanes and stations.

Scenario V also removed competing matatu routes from the mixed traffic lanes, and therefore would have the maximum impact on decongesting the mixed traffic lanes as well. In addition to performing well in regards to the number of passengers attracted and the overall trip time, this scenario draws passengers off the matatu routes and onto the BRT because more routes have been converted into BRT routes, making for faster, more convenient trips.

The trunk-feeder scenarios showed no significant operational advantage over direct services, and would have the following disadvantages:

- Higher infrastructure costs, as it would require large transfer terminals and interchanges, and
- Lower bus flows inside the BRT, and much higher bus flows outside the BRT (in the same roadway) much lower ridership on the BRT and therefore lower operational revenue

5.6.1 Basic cost-benefit analysis of each scenario

By focusing on those elements that vary significantly from one scenario to the other, we can also compare the relative rate of return of each scenario. As the costs are focused on those that vary and not necessarily on all costs, this estimate should not be used for the purpose of full project feasibility appraisal. However, it should be sufficient to help make a service plan decision.

			Comparison of Five Service Plan Scenarios				
Scenario		**Baseline**	**I**	**II**	**III**	**IV**	**V**
Description	**Cost/Unit (USD)**	**Existing**	**Trunk & Feeder, no CBD**	**Direct Services, no CBD**	**Trunk & Feeder, CBD**	**Direct Services, CBD**	**Direct Services, CBD + Langata**
Benefits Calculation							
Matatu Trips		966,213	661,320	575,055	646,213	532,800	456,128
BRT Trips		0	304,893	391,158	320,000	433,413	510,085
Generalized cost (time per passenger)		78.36	76.71	74.13	74.4	71.9	70.9
Generalized cost savings per passenger		0	1.65	2.69	3.96	6.46	7.46
Peak hour generalized benefit (minutes)		0	159,425	260,072	382,620	624,174	720,795
Peak hour generalized benefit (Ksh)			304,502	496,738	730,805	1,192,172	1,376,718
Daily benefit (Ksh)			1,827,012	2,980,429	4,384,829	7,153,029	8,260,310
Annual benefit (Ksh)			548,103,649	894,128,679	1,315,448,756	2,145,908,830	2,478,092,859
Estimated annual benefit (USD)			$ 5,592,894	$ 9,123,762	$ 13,422,946	$ 21,897,029	$ 25,286,662
PV 12 Years @ 5%			$ 49,571,230	$ 80,866,199	$ 118,970,952	$ 194,078,877	$ 224,122,047
Cost Calculation							
# BRT Vehicles		0	284	352	343	335	385
# Articulated 18 meter buses		0	71	241	93	206	266
Total cost of 18 meter buses (USD)	$ 450,000		$ 31,950,000	$ 108,450,000	$ 41,850,000	$ 92,700,000	$ 119,700,000
# 12 meter buses		0	213	111	250	129	119
Total cost of 12 meter buses USD	$ 250,000		$ 53,250,000	$ 27,750,000	$ 62,500,000	$ 32,250,000	$ 29,750,000
Total Bus Cost (USD)			$ 85,200,000	$ 136,200,000	$ 104,350,000	$ 124,950,000	$ 149,450,000
Kilometers of Trunk Infrastructure		0	16.7	16.7	19.4	19.4	20.9
Busway Cost (USD)	$ 2,500,000		$ 41,750,000	$ 41,750,000	$ 48,500,000	$ 48,500,000	$ 52,250,000
Stations	$ 550,000		48	48	53	53	55
Additional Sub-Stations	$ 350,000		8	11	21	22	22
Total Station Cost (USD)			$ 29,200,000	$ 30,250,000	$ 36,500,000	$ 36,850,000	$ 37,950,000
Transfer stations needed		0	6	0	6	0	0
Large (at Terminus or trunk - trunk transfer)	$ 3,000,000		$ 12,000,000	$ -	$ 12,000,000	$ -	$ -
Small (intermediate, 1 or 2 feeders)	$ 400,000		$ 800,000	$ -	$ 800,000	$ -	$ -
Land aquisitoin large out of town (terminal)	$ 5,000,000		$ 10,000,000	$ -	$ 10,000,000	$ -	$ -
Land acquisition large in town	$ 40,000,000		$ 80,000,000	$ -	$ 80,000,000	$ -	$ -
Land Acuisition small in town	$ 2,000,000		$ 4,000,000	$ -	$ 4,000,000	$ -	$ -
Total Transfer Facility Cost			$ 106,800,000	$ -	$ 106,800,000	$ -	$ -
Total Estimated Capital Cost		0	$ 262,950,000	$ 208,200,000	$ 296,150,000	$ 210,300,000	$ 239,650,000
Rate of Return			0.188519605	0.388406334	0.401725316	0.922866748	0.935205703

Table 12: Cost, Benefit, and Rate of Return comparison of Five Service Plan Scenarios[3]

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[3] **Matatu Trips**: The calculation of net user benefits done here includes the generalized cost savings accruing to all transit passengers in the corridor. No effort was made to calculate the impact on mixed traffic generalized travel cost. The passengers that elect to stay on matatus are assumed to face the same travel time as before the project, and the impact of the project on mixed traffic is assumed to be neutral. However, the largest impedance factor for mixed traffic is the number of matatus remaining in the mixed traffic lanes after the project begins. As this is a function of the number of trips that can be captured by the new BRT system, the number of trips remaining on matatus has been retained as an indicator of the level of adverse mixed traffic impact, but it is not further calculated. Were the costs of the project to mixed traffic calculated, these costs would be higher (and benefits lower), the greater the number of trips remaining in matatus.

BRT Trips: Number of passengers captured by the new BRT system. Varies according to service scenario.

Generalized Cost: Generalized cost of the average trip per transit passenger, whether they are on the BRT or on a matatu, expressed in units of time. Our field research indicated that the value of time in Nairobi is 1 Ksh = 0.52333 minutes. The generalized cost of the average existing trip was first calculated by adding in-vehicle (matatu) time + 2 * waiting time (standard waiting factor) + 3 * walking time (standard walking factor for Africa) + the fare equivalent, for which we used 50 Ksh for the matatu trip. For forced transfers, we used 5 minutes for matatu transfers and 3 minutes for the BRT transfers, based on observed values in most systems. We then ran each scenario using the same assumptions, but assuming 70 Ksh for the future BRT trip. These costs were converted into their time equivalent (50 Ksh = 26.17 min, and 70 Ksh = 36.63 min). The same assumptions were applied to each scenario.

As can be observed, any of the scenarios show very robust benefits that can easily justify the projected costs, with rates of return well above what the World Bank is generally looking for (12% or so).

Generalized cost savings per passenger: The difference between the generalized cost of the trip under the scenario and the baseline cost of the trip, so it reflects the generalized benefit per passenger expressed in minutes.

Peak hour generalized benefit (minutes): Daily transit trips were converted into peak hour trips to show the peak hour benefits, because the benefits primarily occur only during peak hours.

Peak hour generalized benefit (Ksh): The peak hour aggregate benefits expressed in Ksh using the value of time of 1 Ksh = 0.5233.

Daily benefit (Ksh): To convert peak hour into daily benefit, a multiplier of 6 was used. Taken from empirical observation, and reflects the fact that the peak hour is generally about 1/10 of daily demand, but the time savings benefits are primarily accrued during the peak 3 hour morning and evening period. With more data we could improve upon this estimate, but as the same factors are used for each scenario it is not necessary for purposes of comparison between scenarios.

Annual benefit (Ksh): Converts daily benefit into annual benefit by using a multiplier of 300, which is a standard multiplier. It could be improved upon with local data but is sufficient for comparison purposes.

Annual benefit (USD): Converts annual benefits from Ksh to USD using current exchange rates

PV 12 Years @ 5%: As BRT projects normally amortize the life of the buses over 12 years and buses are one of the major capital investments, we normally define the project life for 12 years. The infrastructure should last longer, but it doesn't matter for purposes of comparison. This present value calculation reflects the fact that the benefits are accrued on an annual basis, so we took the present value by assuming a stream of equal benefits over 12 years at a 5% discount rate (the opportunity cost of money).

 # Articulated 18 meter buses: Varies by service scenario and optimized based on the projected demand on each route and off trunk corridor conditions.

Total cost of 18 meter buses (USD): Assumed to be $450,000 per bus. This was roughly the cost of the landed articulated buses for Rea Vaya in Johannesburg. This could be replaced with a better figure if available but is within $100,000. Lower cost buses can be found from China and India but with a shorter lifespan. As the same costs were used by scenario, inaccuracy here should not distort significantly the outcome of comparative analysis.

 # 12 meter buses: Varies by service scenario.

Total cost of 12 meter buses (USD): Assumed to be $250,000 which was roughly their cost in Johannesburg. As above with 18 meter buses.

Busway cost (USD): Assumed to be $2.5 million per kilometer, based on the *BRT Planning Guide* Infrastructure Cost Calculator. As each scenario uses the same assumptions, variances will not distort the outcome.

Stations: The number of stations is taken from the service plan and the infrastructure plan.

Additional sub-stations: Varies by service scenario. Each station is assigned a number of sub-stops based on the scenario-specific projected boarding and alighting numbers, and they are designed with enough sub-stops to avoid saturation. These vary somewhat by scenario based on different demand and different services offered.

Total station cost (USD): The cost of a station and a sub-station is taken from the *BRT Planning Guide* Infrastructure Cost Calculator.

Large (At terminus or trunk-trunk transfer): The number of large transfer terminals and their cost is determined by the service plan. These are stations where a large number of feeder buses meet to transfer passengers to a trunk facility. The trunk and feeder scenarios all require four large transfer stations, two and the ends of the corridor on the A104, and two in the CBD where the BRT Corridors I and II cross future corridors. The cost of a transfer station is taken from the *BRT Planning Guide* Infrastructure Cost Calculator. A large transfer facility is estimated to cost $3 million. Small (Intermediate, 1 or 2 feeders): Varies by service scenario. These are terminals where one or two feeders joint the trunk corridor. There are two in the trunk and feeder service proposals, and their estimated cost of $400,000 is taken from the *BRT Planning Guide* Infrastructure Cost Calculator.

Land acquisition large out of town (terminal): Land acquisition for a transfer terminal is one of the main costs of a transfer terminal. They are usually located near the end of the BRT corridor. Usually at the end of a BRT corridor, land is not that expensive. Based on empirically observed averages, the *BRT Planning Guide* Infrastructure Cost Calculator estimates $5 million for a large transfer terminal out of town. Land values in Nairobi are reasonably high, so this seems plausible. A proper costing would require sizing the facility to the service plan and the location of equivalent properties and their sale cost.

Land acquisition large in town: Land acquisition is required to build a very large station that would allow a large volume of passengers to transfer from the two trunk services on the A104 to two future BRT Corridors that cross it in the CBD. Such transfer facilities are difficult to estimate the costs for, but as the land is in the heart of Nairobi, we estimate each will cost $40 million.

Land acquisition small in town: Land acquisition is required for two small transfer facilities in the trunk and feeder scenario, and both of these are in town. We estimate here that the land would cost around $2 million but this could be replaced with more accurate data if available.

Rate of return: Calculated by taking the present value of the string of user benefits and dividing it by the total capital cost. Someone with more familiarity with the way the World Bank does Economic Rate of Return calculations in the transit space should be able to take the information presented here and put it in more standard World Bank format. For comparison purposes this should give a reasonable estimated IRR comparison for each of the scenarios.

However, the capital costs for the trunk and feeder scenarios are much higher largely because of the need to acquire land and construct six transfer stations. This adds an estimated $106.8 million to the cost of all trunk and feeder scenarios (though some of this is offset by smaller fleet sizes due to a much lower ridership).

In the scenarios with infrastructure in the CBD, that infrastructure adds only $2.7 million in busway costs and about $6.5 million in station costs, so about $9.2 million total. We do not foresee the need for extensive land acquisition in the CBD under the direct services scenarios, as the right-of-way is already quite wide. For this initial investment, about $70 million more is achieved in user benefits in the trunk-feeder scenario, and more than $110 million a year in additional benefits in the direct service scenario. The capital cost in the direct service scenarios with CBD (Scenarios IV & V) for buses drops because it runs services in highly congested downtown streets, and increasing these speeds significantly reduces the amount of fleet needed. The CBD section has the highest rate of return of any capital investment in the corridor.

Note that the rate of return is far better for the direct service scenarios, and for all of the scenarios including the CBD infrastructure, and somewhat better still if Langata is included. This, once again, points to Scenario V as being the best investment.

5.7   BRT station locations and sizing

BRT station locations were proposed as part of the service planning process, but prior to the modeling. They were determined by considering the initial placement done by each consultant and making modifications based on the following:

- Station location proposals made by the design consultants (GIBB, COWI and ESER),
- Current passenger boarding and alighting locations obtained from 2013 transit field surveys,
- CBD access analysis,
- Area density and accessibility, and
- Typical station spacing between 500 and 800 meters.

The CBD access analysis and area density and accessibility analyses, found in ITDP's 'Nairobi Infrastructure & Intersection Recommendations Detailed Report', helped to determine areas of the CBD that do not currently have sufficient service. This lack of service is due to restrictions on the flow of buses and matatus on certain roads in the CBD, as well as the flow of pedestrians around the CBD.
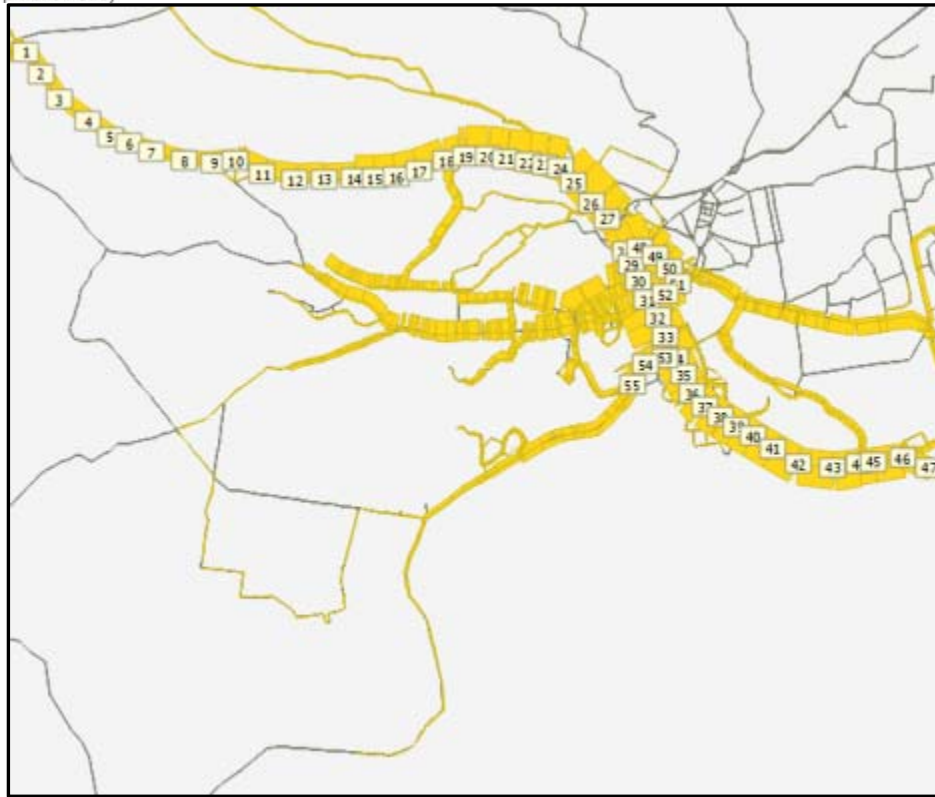
Figure 47: Proposed station stops along A104, CBD, and Langata Road

The station by station passenger boarding and alighting volumes, calculated by the model, enable us to determine the optimal size for each station and thus, provide station sizing recommendations. Sizing a BRT station so that it does not saturate is a critical element in achieving high capacities and high speeds along a BRT corridor. High station saturation has an inverse effect on overall speed, as shown in the graph below.
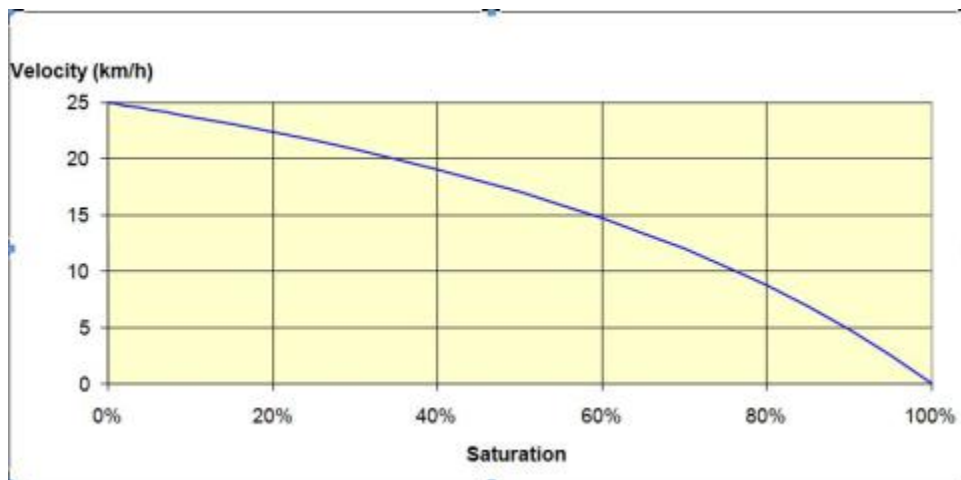

Figure 48: High station saturation has an inverse effect on speed

In general, stations should be at less than 40 percent saturation or else the risk of congestion increases significantly and there is a high risk of deterioration of service quality. Station saturation is calculated by:

Saturation = (A*Freq.bus + B*Boardings + C*Alighting)/3600

A=Fixed Dwell time; 13 seconds for Standard buses and 15 seconds for Articulated buses

B= Boarding Time per passenger; 0.5 for both Standard and Articulated Buses

C= Alighting time per passenger; 0.5 for both Standard and Articulated Buses

Knowing the passenger boarding per station per route, we were able to calculate the saturation levels at each station. Where stations will face 40 percent or greater saturation, we recommend including multiple "sub-stops." A typical station has two docking bays. Adding more docking bays helps to drop the saturation level. After two docking bays, additional docking bays are typically added via sub-stops, which is an additional station module with enough space for a bus to easily pull in and pull out if there is another bus at the adjacent sub-stop.

Figure 49: Multiple docking bays and sub-stops not only increase the capacity of a station, they help stations provide multiple services at the station as well. Source: BRT Standard

Under our recommended scenario, most BRT stations along A104 are calculated as having acceptable saturation levels and do not need additional sub-stops. However, the stations in the CBD have a saturation of between 65 and 145 percent and require additional sub-stops. One of the primary reasons ITDP recommended a full BRT ring through the Nairobi CBD was to increase the number of stations able to handle CBD-bound passengers, thereby distributing demand across several stations. With 9 full BRT stations in a ring

around the Nairobi CBD, the CBD-bound demand on the A104 is well distributed and minimizes walking times for passengers boarding and alighting the BRT system. The maximum number of sub-stops in this scenario is 3.
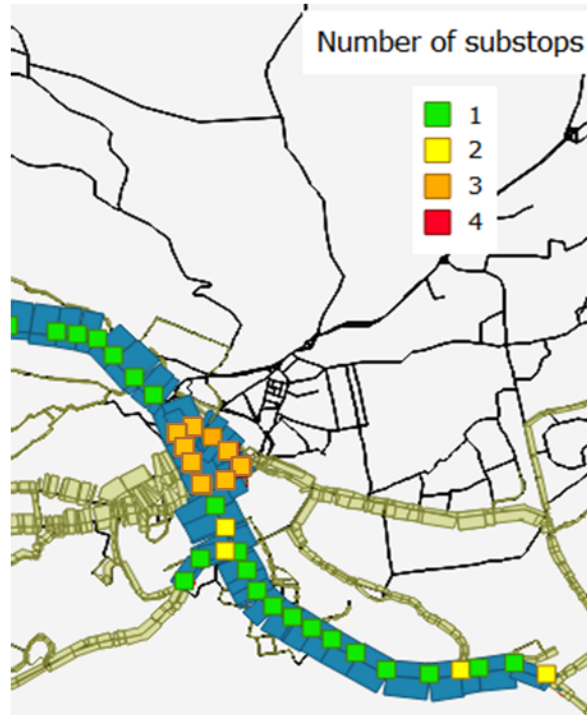

Figure 50: With BRT infrastructure and stations in the CBD, demand is can be distributed throughout 9 CBD stations, thus requiring fewer sub-stops

The alternative proposal – to have only 4 stations along the A104 – would result in all of the demand concentrated in only 4 stations, and these stations would, thus, need to be larger, including up to four sub-stops at at least two stations.
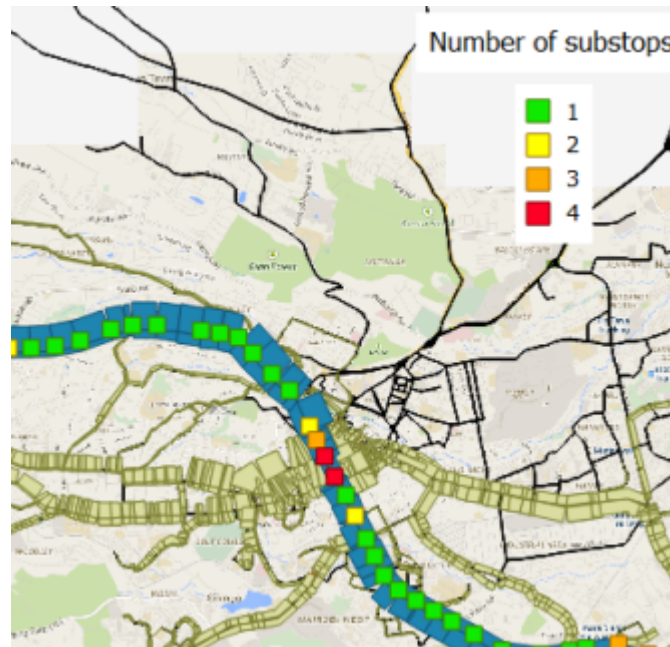
Figure 51: Without BRT infrastructure and stations in the CBD, demand is concentrated at only a few stations on Uhuru Highway, thus requiring more sub-stops

Further, if we consider a future where additional corridors are built and transfers between BRT routes are forced, these stations could grow to having four sub-stops each with one station as large as six sub-stops.
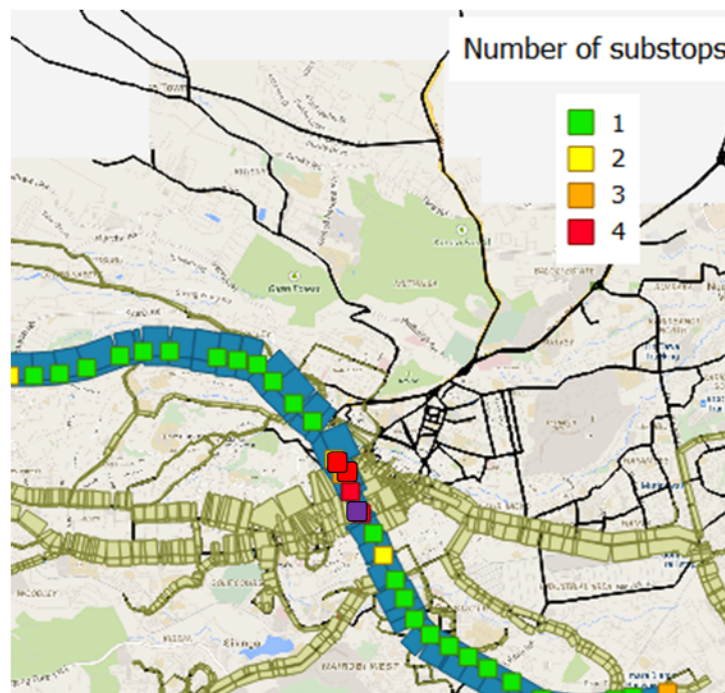
Figure 52: Number of sub-stops required in a trunk-only system with multiple corridors far exceeds international best practice

To compare this with other systems internationally, we look at the following chart:

Most station substops

City	Substops	Note
Bogota	4	(Jul-13)
Guangzhou	4	Tiyu Zhongxin & Shidajida Stations (Sep-14)
Cali	3	(Jul-13)
Lima	3	Uni Station (Jul-11)
Brisbane	2	Some station have more, but at most 2 are functional (Feb-14)
Hefei	2	(Mar-13)
Johannesburg	2	(Jul-12)
Lanzhou	2	Xi Zhan & Peili Guangchang designed 3, but operated 2 (Oct-13)
Leon	2	(Jun-13)
Mexico City	2	(Jul-13)
Ahmedabad	1	(Sep-12)
Amsterdam	1	(Jul-11)
Bangkok	1	(Oct-11)
Beijing	1	(Feb-13)
Cape Town	1	(Jul-12)
Changde	1	(Mar-13)
Changzhou	1	(Jul-13)
Chengdu	1	(Oct-14)
Curitiba	1	(Jan-11)
Dalian	1	(Mar-14)
Hangzhou	1	(Aug-11)
Jakarta	1	(Mar-13)
Jinan	1	(Jul-14)

Figure 53: Maximum number of sub-stops for BRT systems around the world. None are as high as the Uhuru Highway-only scenario with trunk-only services

To avoid station saturation and to avoid the significant amount of land acquisition required to build multiple sub-stops, we recommend a careful distribution of stations around the CBD.

5.7.1 Routes included in Scenario V

Careful analysis of demand conditions resulted in 16 different services. These services provide optimal routing for passengers from residential areas to major destinations. The routes are:

BRT Route	Description	Type of Service
B105X	Kikuyu to CBD	Express
B11	Hazina to CBD	Express
B110A	Kitengela to CBD	Express
B110B	Mlolongo to CBD	Express
B12	Highway Estate to CBD	Express
B125	Mbagathi to CBD	Express
B14	Madaraka Estate to CBD	Express
B15	Kijiji to CBD	Express
B23	Kangemi to CBD	Express
B30	Uthiru to CBD	Express
B33	Imara Daima to CBD	Express
B33F	Nyayo Estate to CBD	Express
B33N	Ngummo to CBD	Express
B33U	Utawala to CBD	Local
B34	JKIA to CBD	Express
B48	Kawangware to CBD	Express

Table 13: Scenario V BRT Routes

Route B105X – Express Service
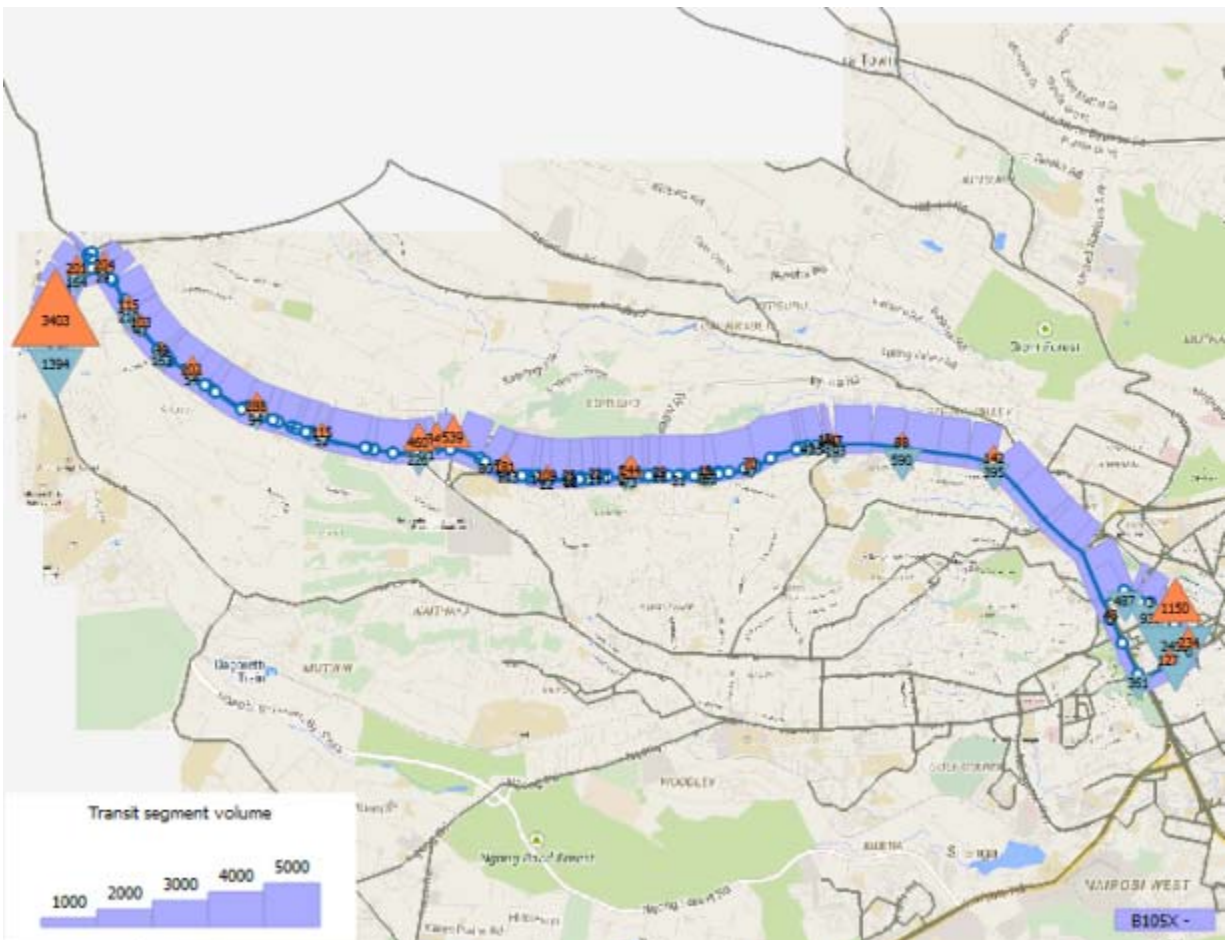
- Express service running from Kikuyu to CBD
- 7,600 passenger boardings during the peak hour.
- Requires an operational fleet of 66 articulated buses.
- Required frequency of 24 buses per hour
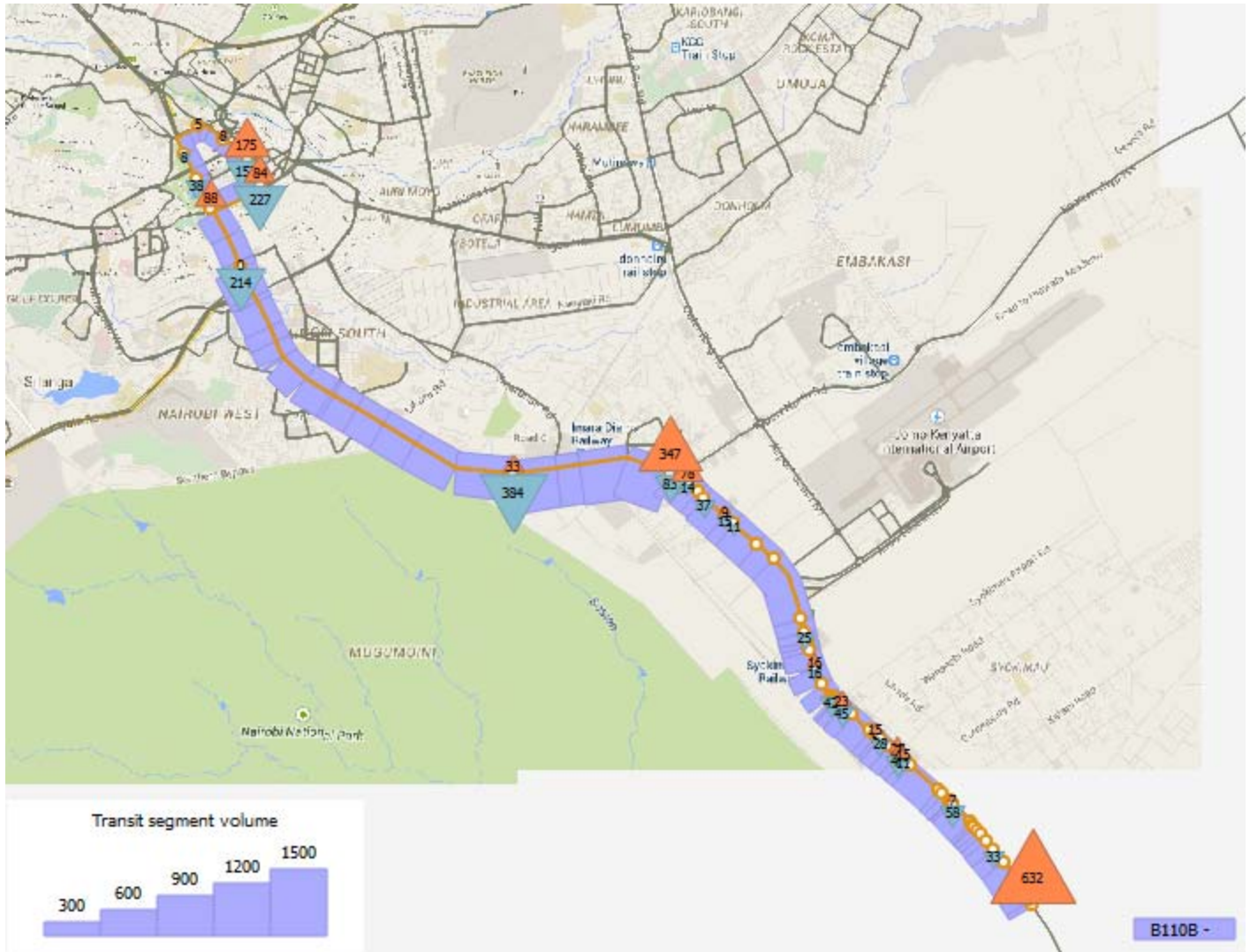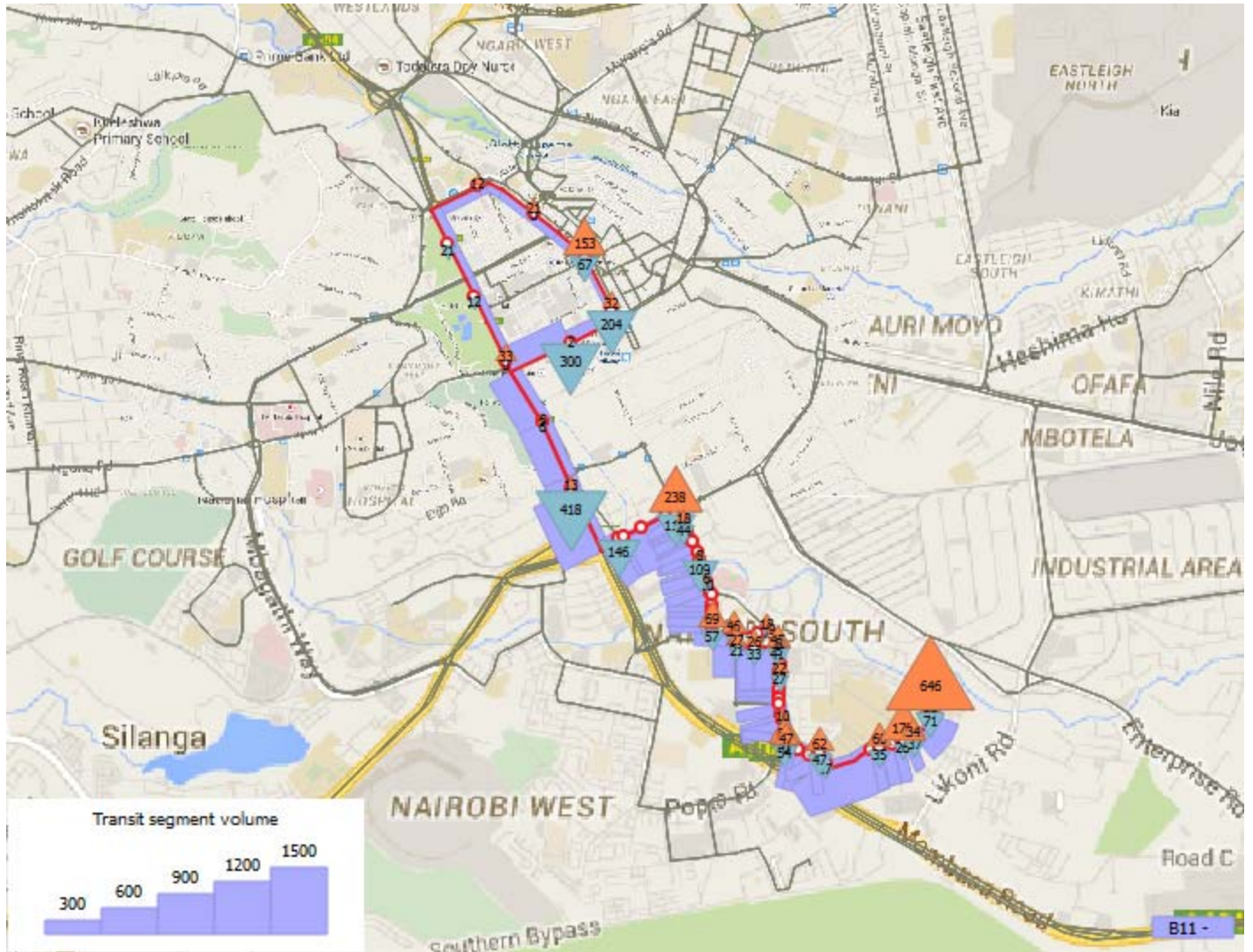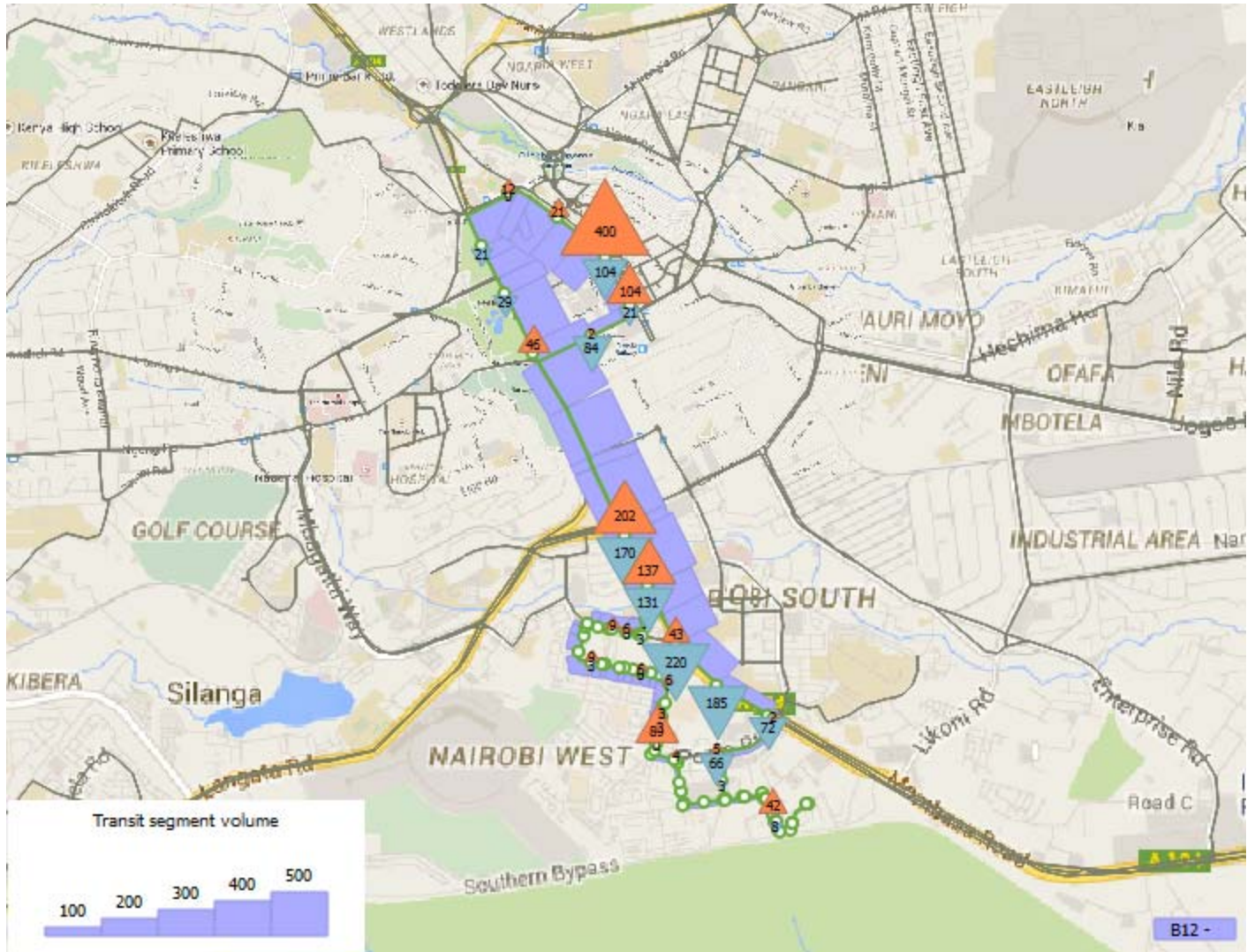
5.7.1.1 Route B30 – Express service
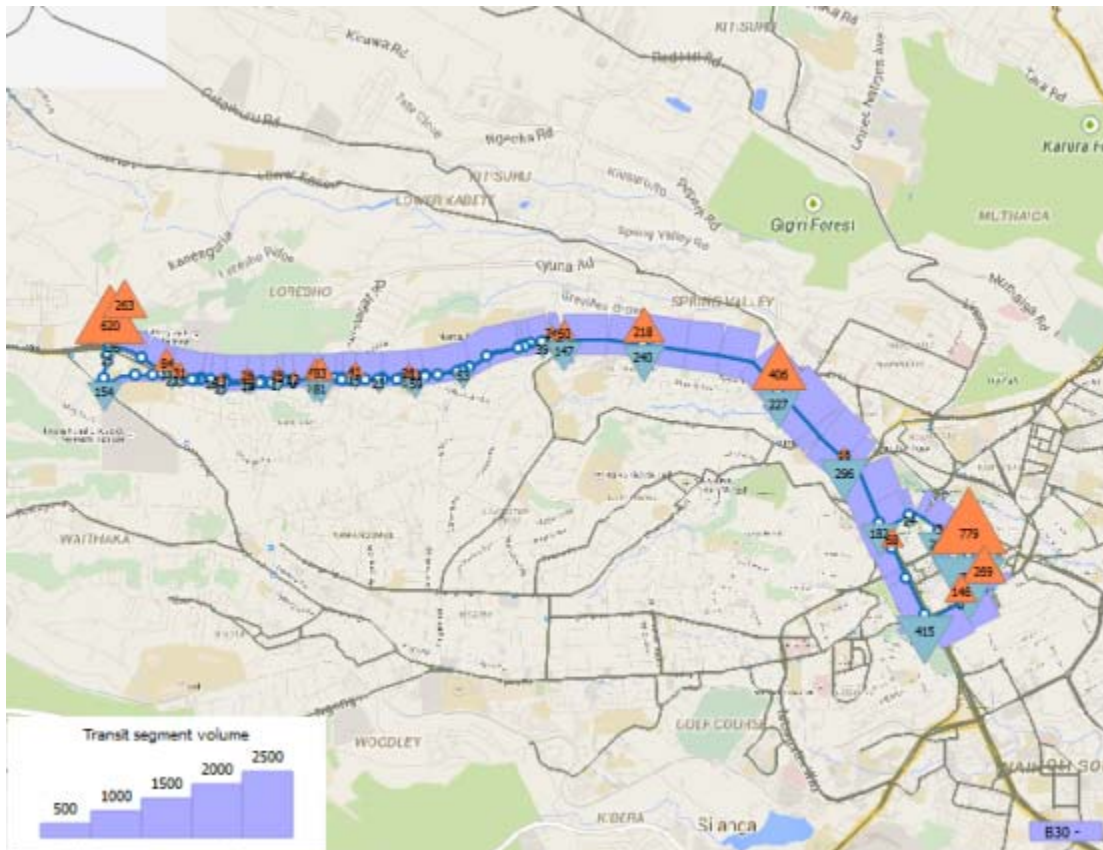
- Express service running from Uthiru to CBD
- 6,100 passenger boardings during the peak hour.
- Requires an operational fleet of 26 articulated buses.
- Required frequency of 17 buses per hour

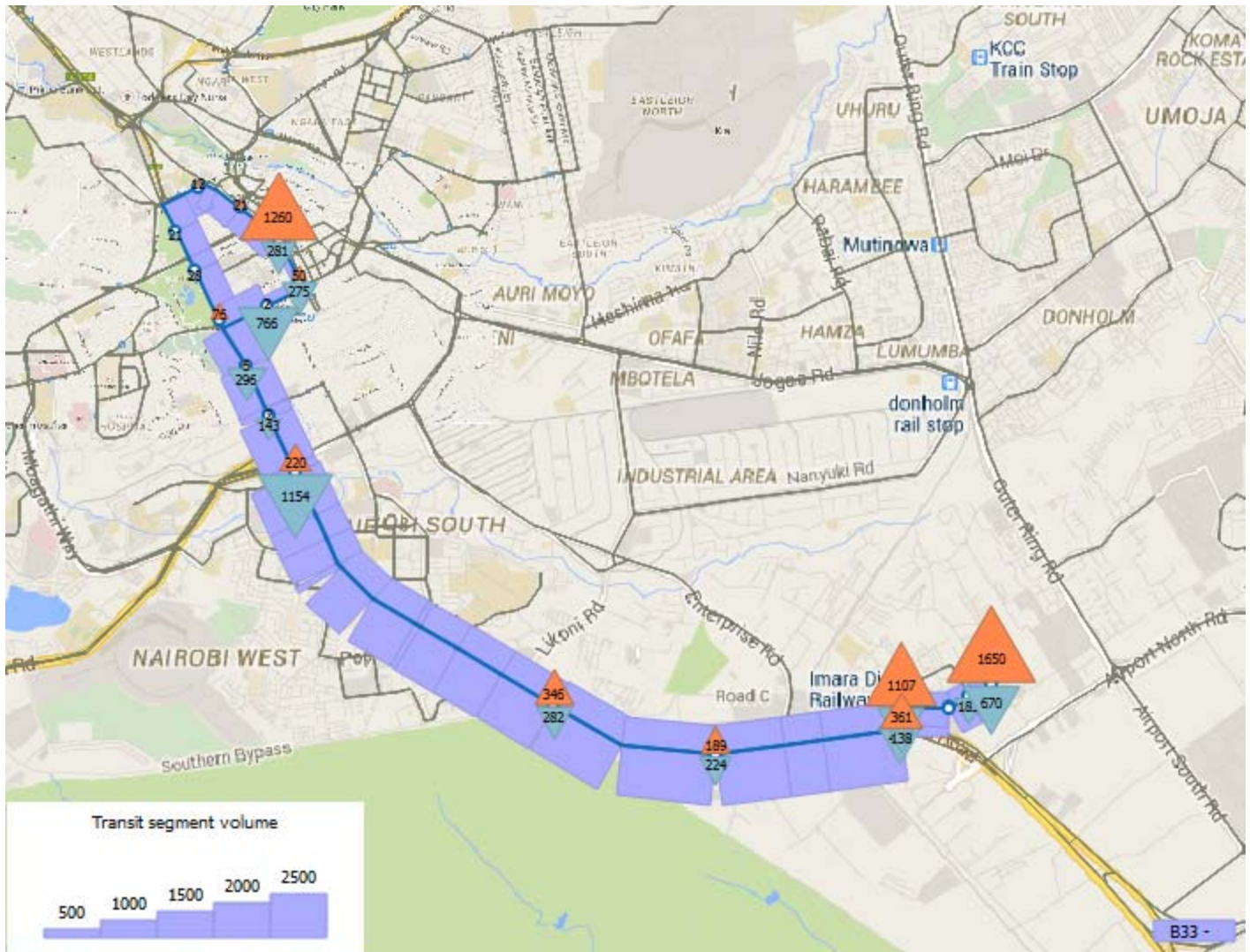*5.7.1.2   Route B23 – Express service*
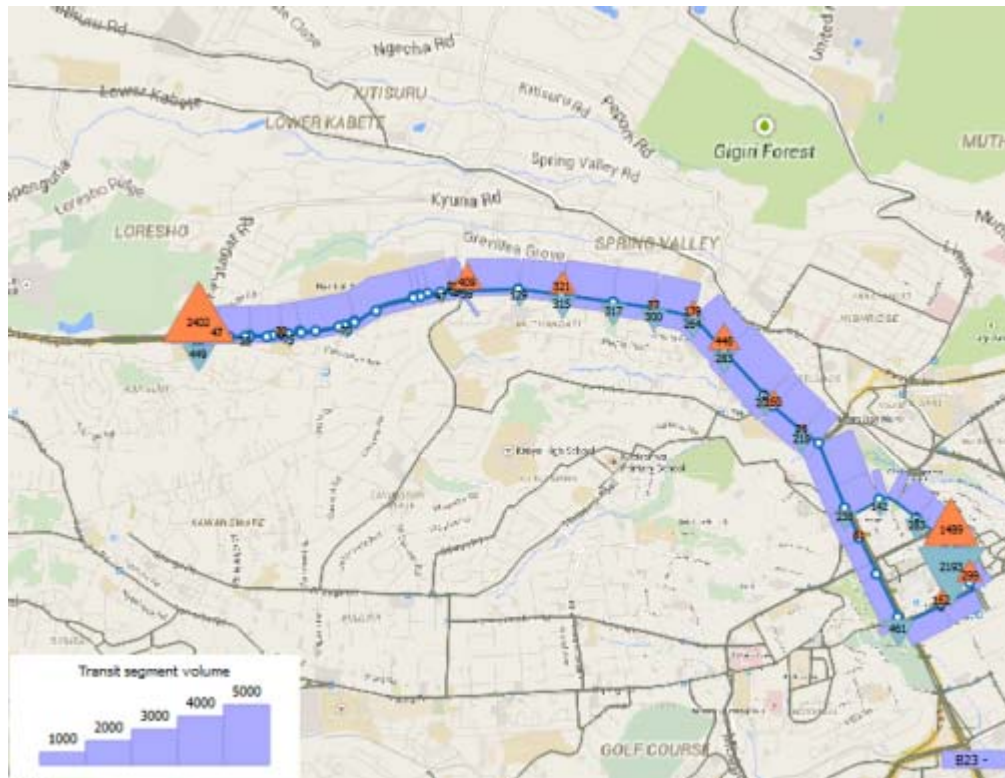
- Express service running from Kangemi to CBD
- 5,700 passenger boardings during the peak hour.
- Requires an operational fleet of 20 articulated buses.
- Required frequency of 19 buses per hour

5.7.1.3 Route B48 – Express service
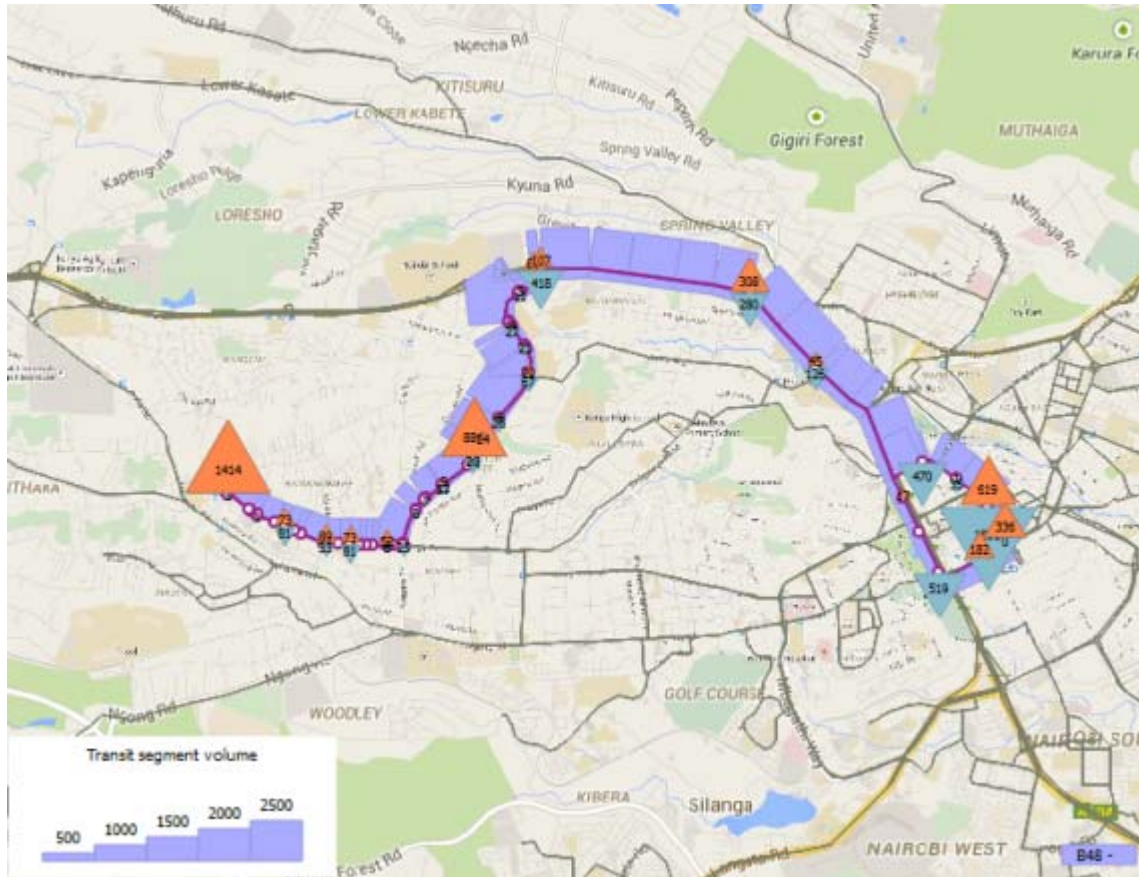
- Express service running from Kawangware to CBD
- 4,100 passenger boardings during the peak hour.
- Requires an operational fleet of 38 articulated buses.
- Required frequency of 16 buses per hour

5.7.1.4   Route B110A – Express service

- Express service running from Kitengela to CBD.
- 2,300 passenger boardings during the peak hour.
- Requires an operational fleet of 31 standard buses.
- Required frequency of 11 buses per hour
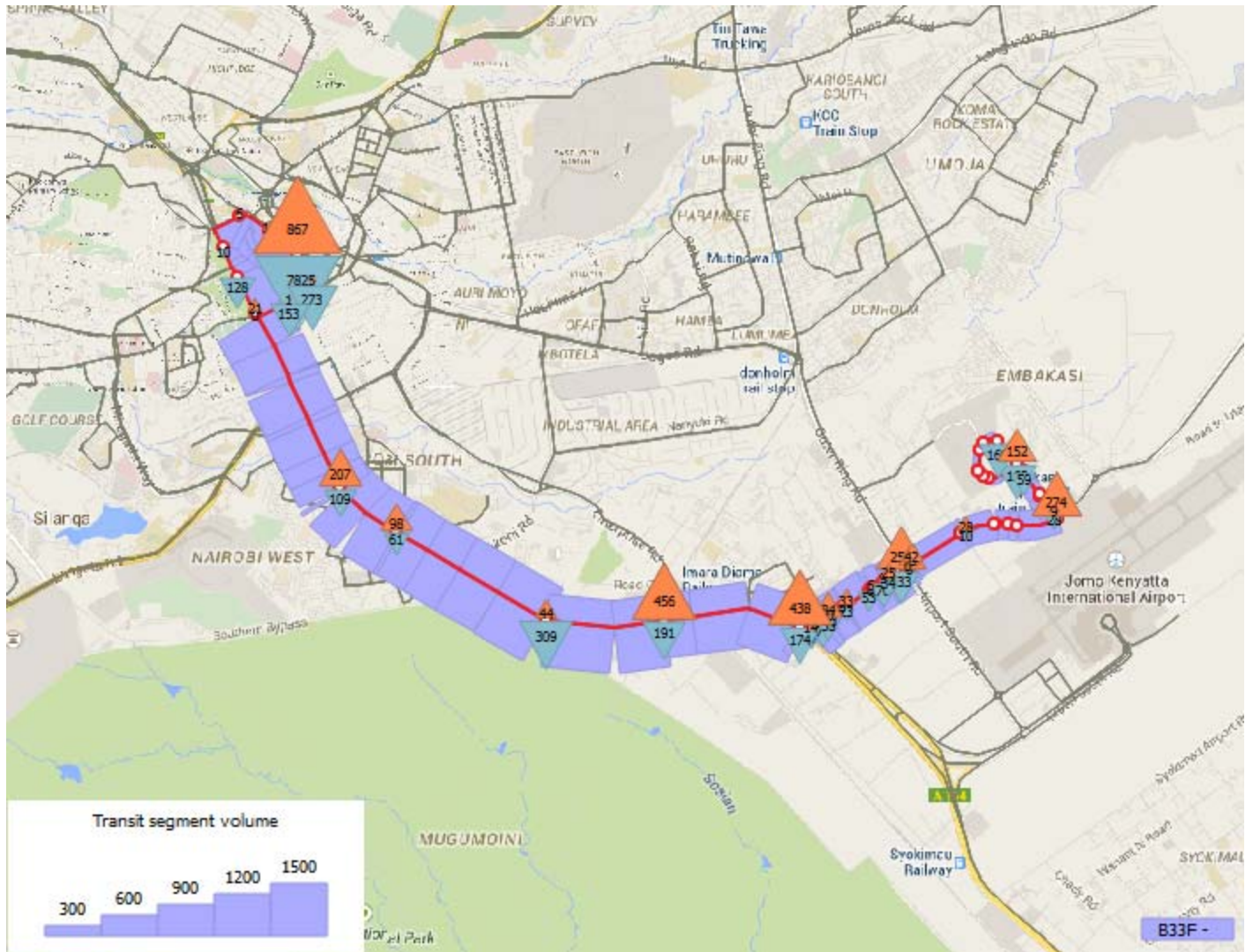
5.7.1.5 Route B110B- Express service

- Express service running from Mlolongo to CBD.
- 1,600 passenger boardings during the peak hour.
- Requires an operational fleet of 19 standard buses.
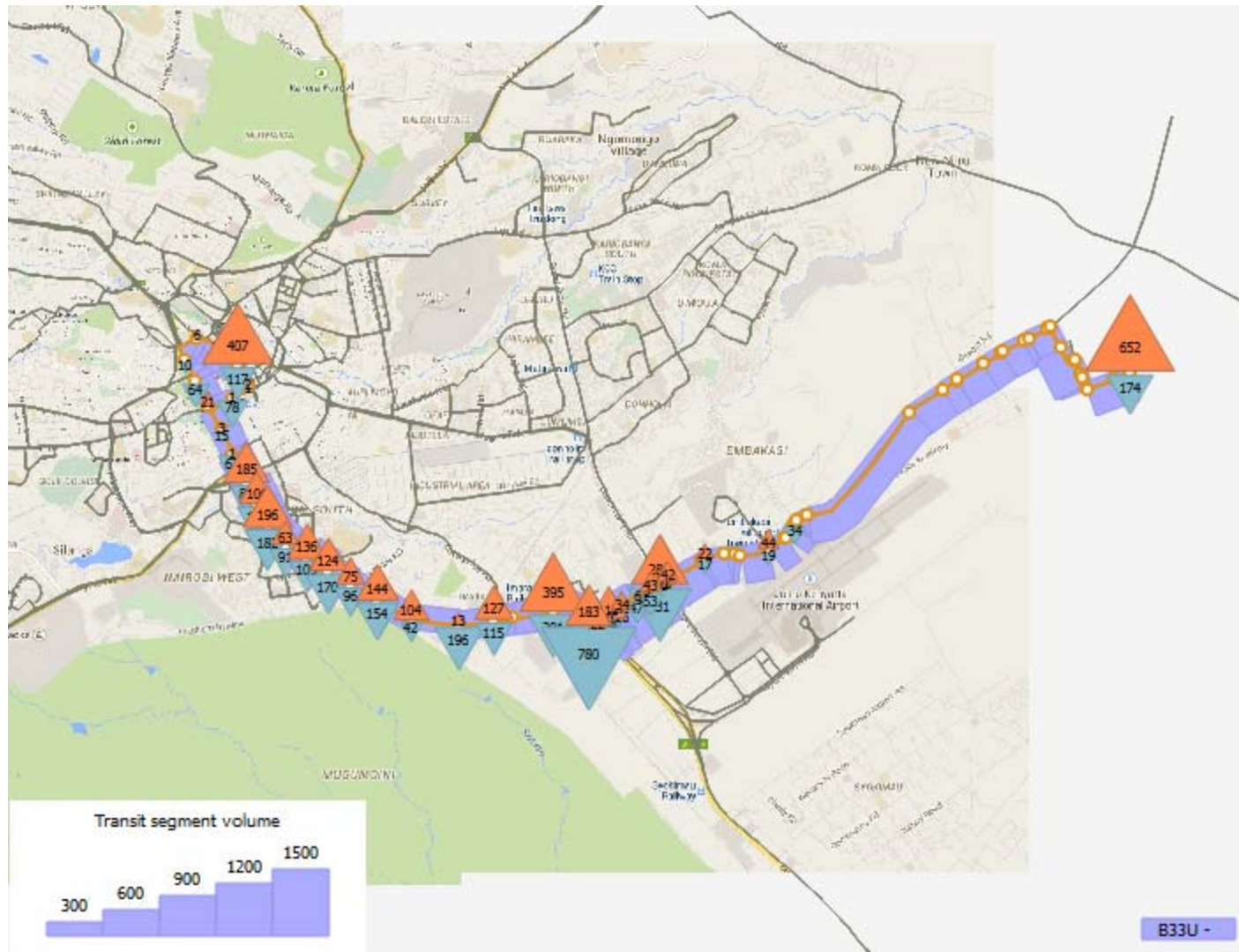- Required frequency of 10 buses per hour

- Express service running from Hazina to CBD
- 2,000 passenger boardings during the peak hour.
- Requires an operational fleet of 13 standard buses.
- Required frequency of 11 buses per hour

- Express service running from Highway Estate to CBD
- 1,100 passenger boardings during the peak hour.
- Requires an operational fleet of 9 standard buses.
- Required frequency of 7 buses per hour

- Express service running from Imara Daima to CBD
- 5,300 passenger boardings during the peak hour.
- Requires an operational fleet of 17 articulated buses.
- Required frequency of 18 buses per hour

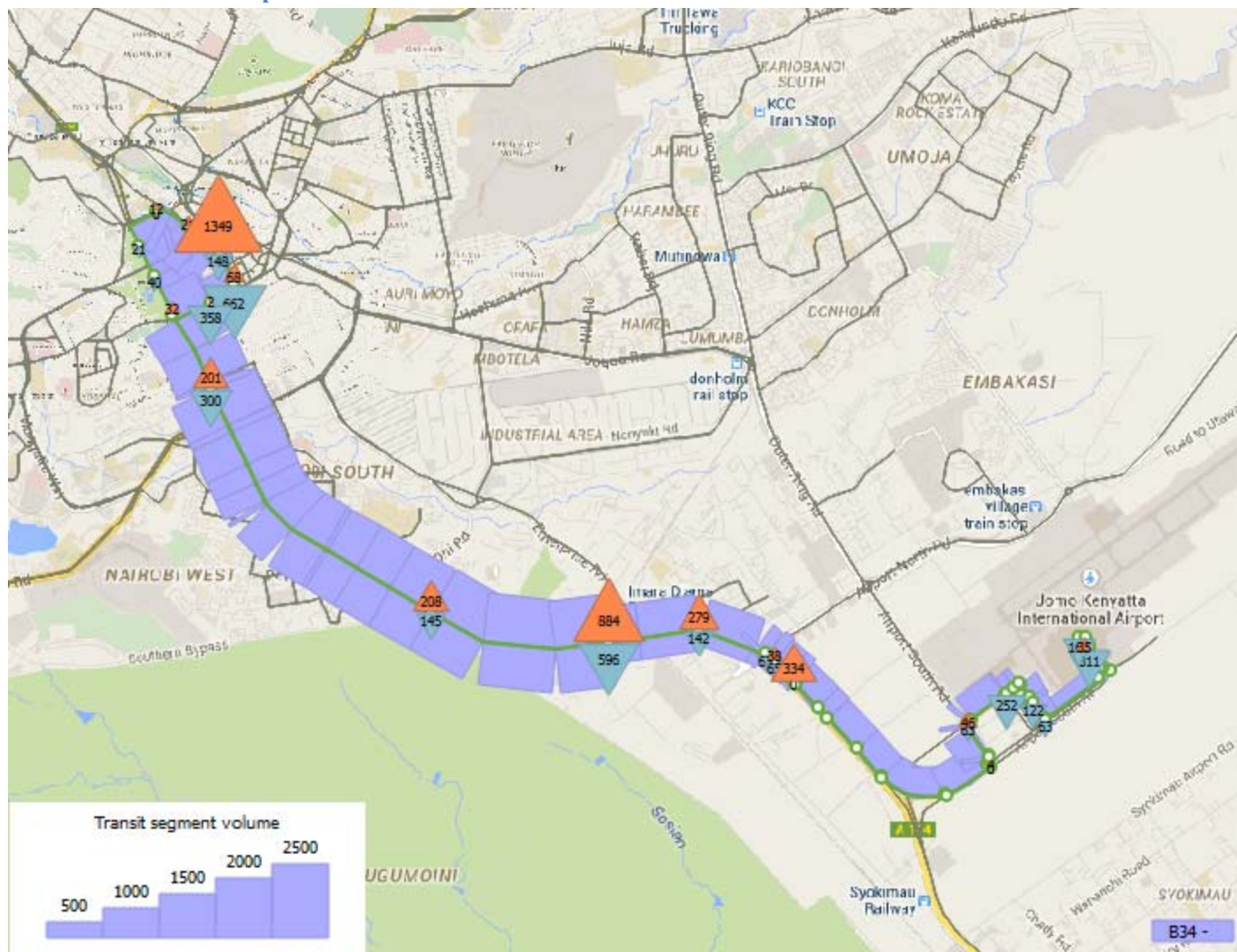### 5.7.1.9   Route B33F – Express service

- Express service running from Nyayo Estate to CBD
- 3,100 passenger boardings during the peak hour.
- Requires an operational fleet of 20 articulated buses.
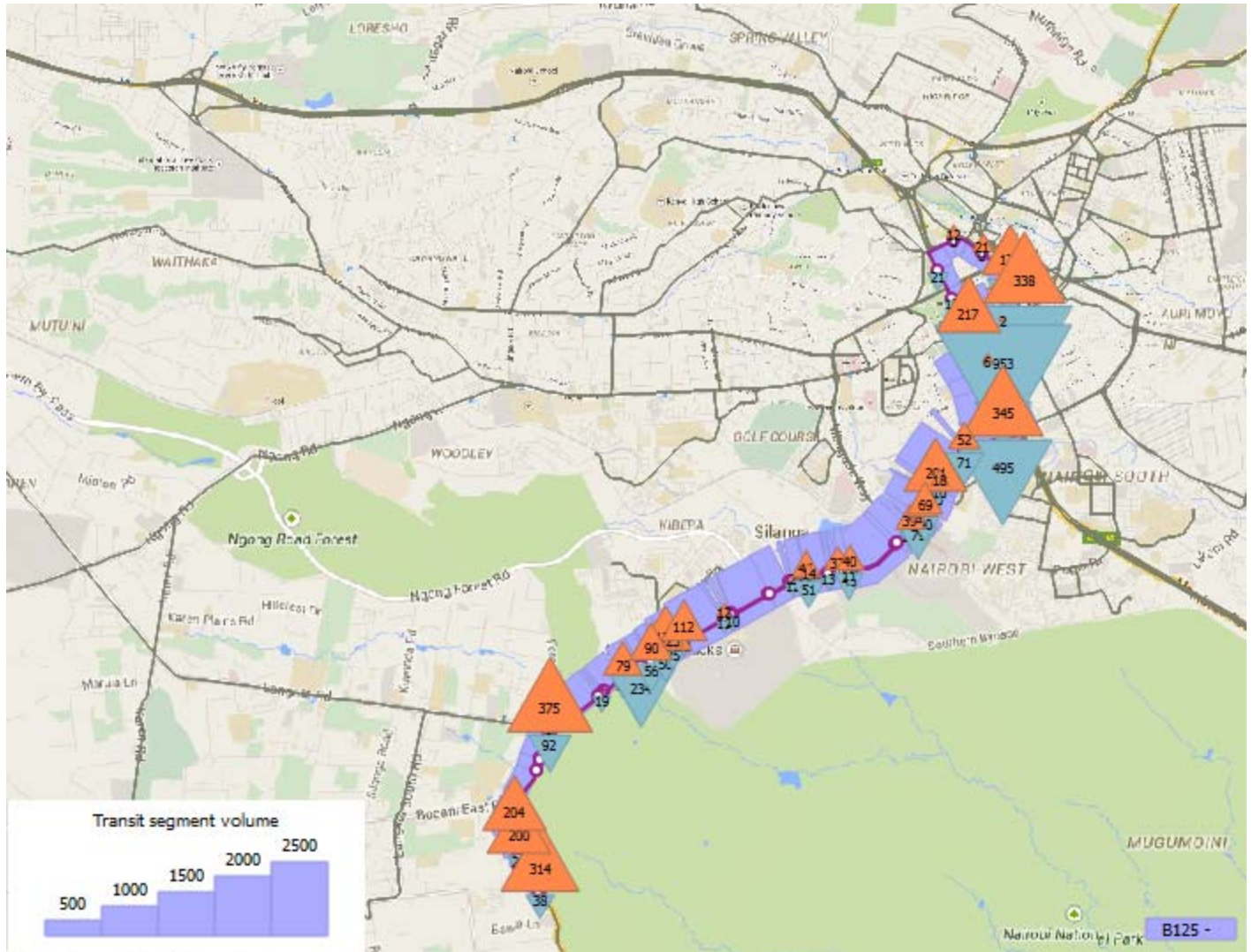- Required frequency of 8 buses per hour

- Local service running from Utawala to CBD
- 3,600 passengers boardings during the peak hour.
- Requires an operational fleet of 40 standard buses.
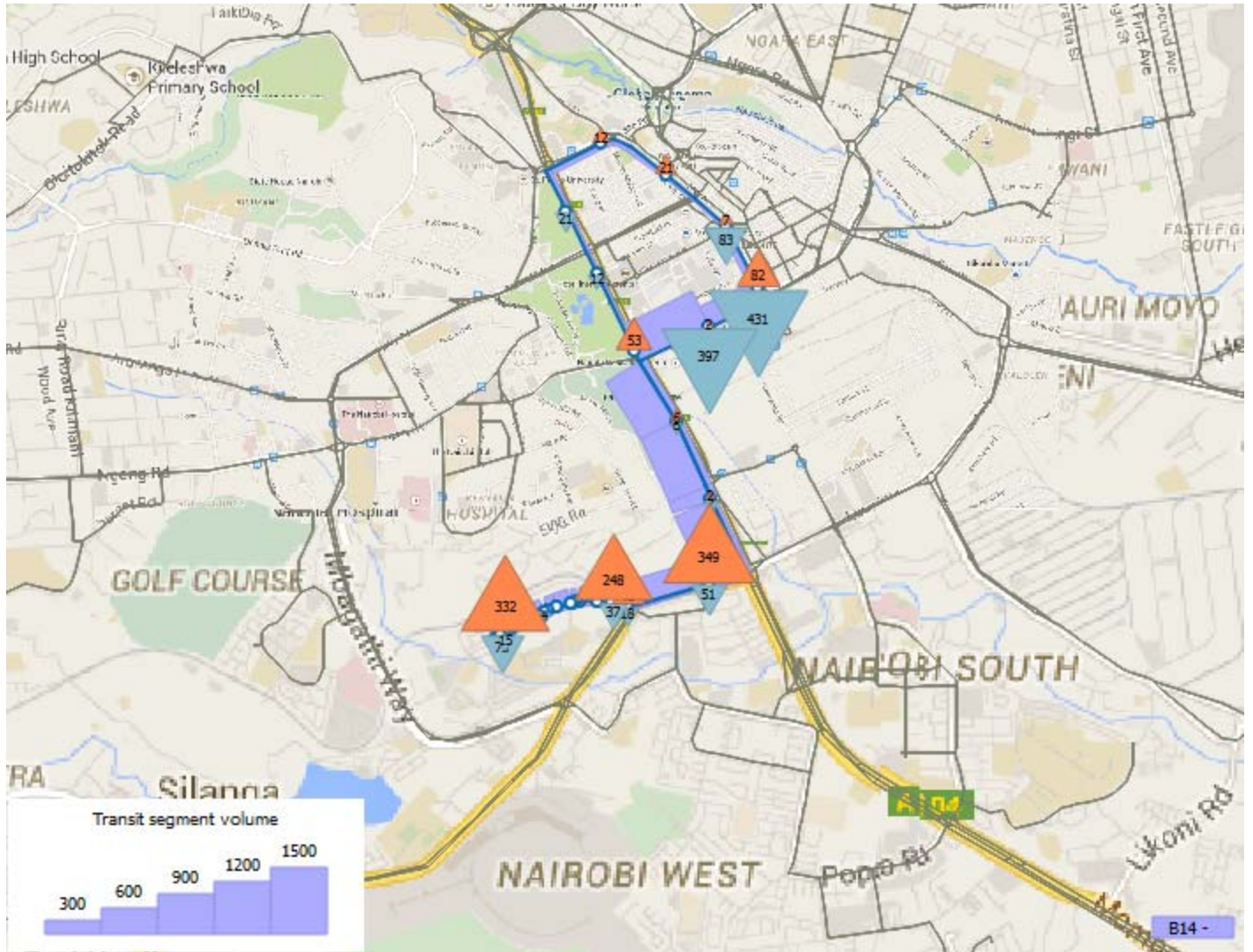- Required frequency of 10 buses per hour

- Express service running from Jomo Kenyatta International Airport to CBD
- 3,500 passenger boardings during the peak hour.
- It requires an operational fleet of 19 articulated buses.
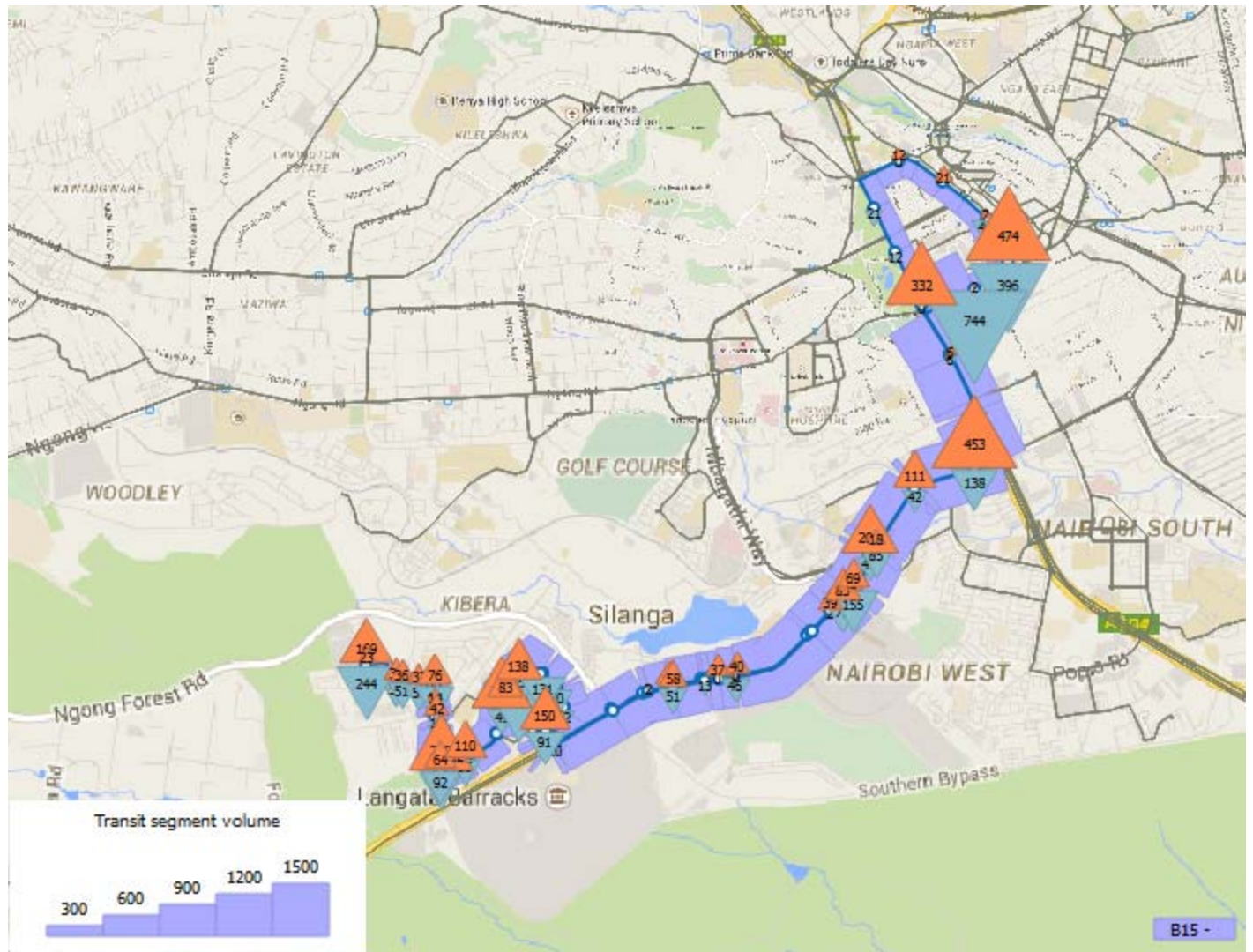- It has a proposed frequency of 10 buses per hour

- Express service running from Mbagathi to CBD
- 3,300 passenger boardings during the peak hour.
- Requires an operational fleet of 29 articulated buses.
- Required frequency of 11 buses per hour

- Express service running from Madaraka Estate to CBD
- 1,200 passenger boardings during the peak hour.
- Requires an operational fleet of 7 standard buses.
- Required frequency of 10 buses per hour

5.7.1.14 Route B15 – Express service

- Express service running from Kijiji to CBD
- 3,600 passenger boardings during the peak hour.
- Requires an operational fleet of 18 articulated buses.
- Required frequency of 8 buses per hour

- Express service running from Ngummo to CBD
- 2,400 passenger boardings during the peak hour.
- Requires an operational fleet of 13 articulated buses.
- Required frequency of 13 buses per hour