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# City-scale Transport Modeling:
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## Abstract

Traffic congestion poses problems for cities around the world, especially in rapidly growing and motorizing cities like Nairobi, Kenya. We show here how we plan to use in the context of Nairobi a new theory that relates the mobility provided by a city's street network to the number of vehicles on the network (including private cars and public transport) and to key aggregate descriptors of both the street infrastructure and the public transport services.

Conventional micro-simulation models require vast quantities of data and produce unreliable detailed results. The new theory asserts that a micro-simulation of a simplified, abstract city resembling Nairobi in the key aggregate descriptors provides reproducible aggregate mobility predictions, and the effort in doing so is orders of magnitude smaller than with the conventional approach. Described in detail are the input data required to construct the idealized network including formal and informal public transport services and to calibrate the simulation model with current demand conditions. The outputs of the model and their practical use for scenario analysis are also discussed.

# 1 Introduction

Transportation is one of the challenges faced by cities around the world, especially as the global population is rapidly urbanizing, and the problems of traffic congestion and gridlock are becoming increasingly severe. Quickly growing cities, like Nairobi, Kenya, are facing streets that are clogged with private automobiles and public transport, such as Nairobi's informal matatu services. This motivates the need to understand the performance and behavior of urban street systems. We summarize here a new modeling approach that shows how urban mobility can be assessed and improved by looking at city-scale performance. This aggregate approach provides reproducible results from observable data in contrast to traditional micro-simulations that are data-intensive yet unreliable.

## 1.1 Nature of Traffic and City-wide Mobility

Traffic on a city-wide street network can be thought of as a collection of vehicles, each moving toward a destination. This can be visualized as a large and complex traffic circle where vehicles enter the circle from an origin and then progress to a destination, interacting with other vehicles, on the way. The goal of a traffic circle (and a city street network in general) is to provide mobility for as many vehicles and people as possible to reach their destinations. The rate at which vehicles reach their destinations is called the outflow, and this represents trips ending either because they reach a destination within the city or they pass out of the region of concern (e.g. central business district). The maximum outflow depends on the infrastructure and control of the street network and the number of vehicles using the streets, but it is not sensitive to the demand.

The relationship between the number of vehicles in the system (accumulation) and the rate of trips reaching their destinations (outflow) is illustrated in Figure 1. It should be intuitive that when few vehicles are using the network, the outflow is low because there are not many vehicles on the network to begin with as shown in green. As the number of vehicles increases, the rate at which trips end also increases until a point indicated by the yellow region. Once too many vehicles are on the streets, they get in each other's way, and travelers are delayed. If vehicles continue to enter the system, this can ultimately decay into a state of perfect gridlock where outflow is low because every vehicle is blocked by those around it. This is represented by the area in red. An interactive animation, "The Nature of Urban Traffic Gridlock," conveys this concept and can be accessed online (*http://www.its.berkeley.edu/volvocenter/gridlock/*).

This curve is similar to the fundamental diagram used by engineers to describe traffic on individual streets (see e.g., Daganzo, 1997), but the city-scale fundamental diagram is more reproducible. The different colored data points in Figure 1 are values from a series of simulations of San Francisco's central business district (Geroliminis & Daganzo, 2007a). Each color represents data from a simulation using different demand inputs. The key observation is that even when traffic demands changed, the outflow of the network varies only with the accumulation of vehicles on the network in a consistent way. The maximum outflow for the street network in the simulation is always associated with the same number of vehicles on the roads, and this point is called the "sweet-spot."

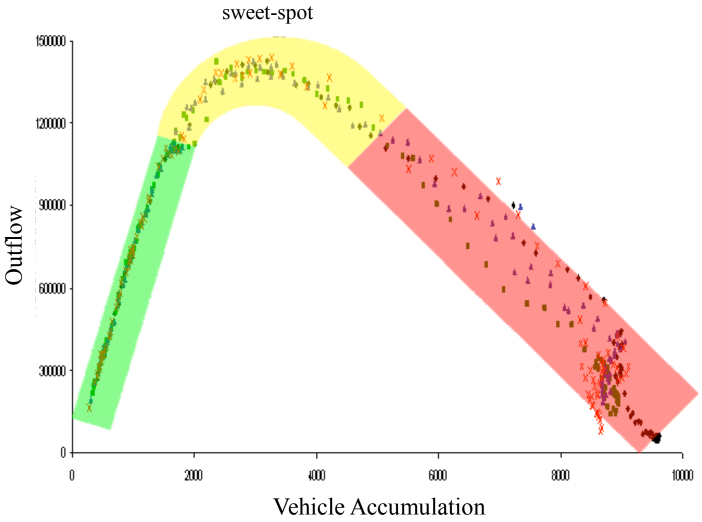


Figure 1. Fundamental diagram of outflow relative to accumulation for a city

## 1.2 Improving City-wide Mobility

The goal of the road network is to move as many people and goods to their destinations as possible, so the network performs best if it is operating at the sweet-spot. One method of improving performance is to restrict entrance into the city when demand exceeds the sweet-spot vehicle accumulation. By controlling the street network so that some vehicles are held back, the system can be kept from decaying into gridlock. The result is that everyone can benefit by reaching their destinations sooner, even those whose access to the city was initially restricted.

Another simulation in Geroliminis and Daganzo (2007a) shows how proper control can increase the number of destinations reached in the same amount of time using the existing physical infrastructure. In Figure 2, the graph on the left shows how the outflow or rate of trips ending slows after the accumulation passes the sweet-spot. On the right, the graph shows a controlled scenario where vehicles are restricted from entering the city so that the sweet-spot accumulation is never exceeded. The outflow in the controlled case never drops, and the total number of trips served is greater than with unrestricted traffic. These ideas are discussed in further detail in Daganzo (2007). The ideas have been experimentally verified with real traffic data from Yokohama, Japan (Geroliminis and Daganzo, 2007b).

Public transport is an important part of providing mobility for travelers in a city. For a system where everyone travels alone by car, increasing the mobility for vehicles is the same as increasing the mobility for people. In real cities, however, many vehicle types use the streets, and public transport vehicles typically carry more passengers than a private car. All vehicles contribute to the traffic conditions on the street as described above, and public transport is delayed along with general traffic when gridlock occurs. Improving the street network's ability to serve person trips depends on how different vehicle types such as private cars, matatus, and buses are served. The city-scale approach can be used to look at how controls for different modes can affect the overall mobility provided.

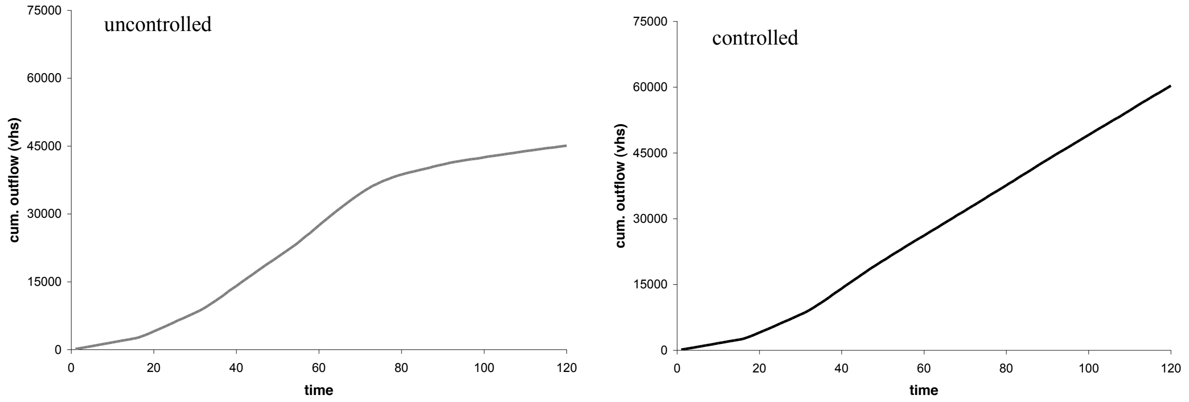


Figure 2. Total number of trips ended (cumulative outflow) versus time when traffic accumulation is uncontrolled (left) and controlled (right)

The proposed aggregate analysis method provides useful results without needing to consider the details of traffic in individual streets in the city. Daganzo and Geroliminis (2007) identifies important factors in determining the macroscopic fundamental diagram of a city's network. They are characteristics of the street network infrastructure, and include basic information about the length and type of streets, number and type of intersections, properties of public transport services, and observable properties of the vehicles. A detailed survey of every street and intersection is not necessary since an idealized network that represents Nairobi with the same aggregate characteristics will perform similarly to the actual network. On the demand side, total demand by time of day and average trip lengths suffice to estimate accumulations and key mobility indicators—geographic variations in demand patterns do not cause significant variation in performance. The following sections describe a simulation methodology and the specific data needed to model a city in this aggregate way.

## 2 What Our Simulation Does and Needs

Simulation is a method of viewing the existing transportation performance in a city and seeing how this performance may change with growing demands. It is not possible to accurately predict the behavior of specific streets or intersections in great detail because there are too many factors involved. What can be done is to look at the performance of individual modes at a city-wide, geographically aggregated level. First a model is built to simulate existing conditions, and then performance can be assessed as traffic demands or controls change.

Conventional micro-simulation methods describe a city in precise detail in an attempt to describe and forecast traffic conditions on every street and through every intersection. The aggregate simulation method we have developed at Berkeley performs a micro-simulation on an abstract representation of a city that shares similar characteristics with the real transportation network. This simulation approach is just as accurate as the conventional approach, but it is less data-intensive. It can be used to assess system-wide effects of changes in demand or traffic control strategies. The simulation predicts neighborhood-wide measures of effectiveness that include average vehicle speed, vehicle stops, delays, vehicle-hours of travel (VHT), person-hours of travel (PHT), vehicle-kilometers of travel (VKT), and person-kilometers of travel (PKT). These measures can then be used to assess the performance of the transportation network on a neighborhood by neighborhood basis for the whole city.

We use a program (CORSIM) that allows us to build a model of a city and its traffic behavior and then simulate the transportation system's performance. An abstracted model of the city's road and public transport network is sufficient for assessing transportation network performance. To be representative, this abstract model must share characteristics with the actual city. Thus, data on the existing road network, travel demands, and public transport operations are necessary. Data describing the existing conditions in the city are required to build a model and validate the simulation. Only with representative data can a simulation of possible changes in demand, traffic patterns, and control produce meaningful results. The construction and use of our simulation model requires six steps:

1. Network Construction
2. Origin-Destination Demand Estimation
3. Public Transport Infrastructure and Operations Modeling
4. Simulation
5. Performance Calibration and Validation
6. Scenario Evaluation

The following sections explain these steps in more detail, both under conventional microscopic methods and with our aggregate method. The difference in data requirements between these methods is illustrated in Table 1 for a hypothetical city shown in Figure 3. In the figure, different colored lines represent streets with different numbers of lanes, the shapes at their intersections indicate different classes of intersections (e.g. controlled by traffic signals, traffic circles, and stop signs), and the shaded regions indicate neighborhoods or analysis zones for the city. More detailed descriptions of what these categories represent are provided in Sections 3 and 4.

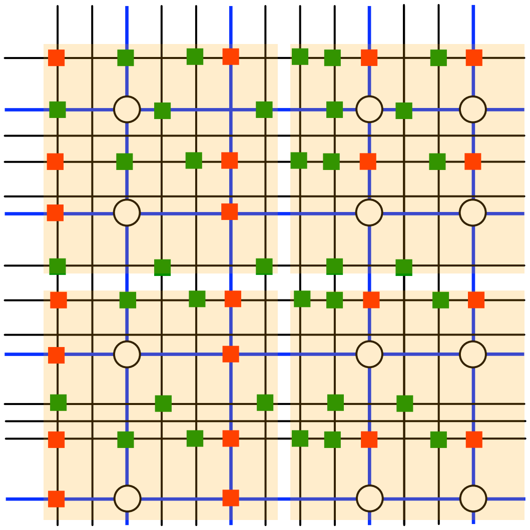


Figure 3. Abstract representation of a hypothetical city

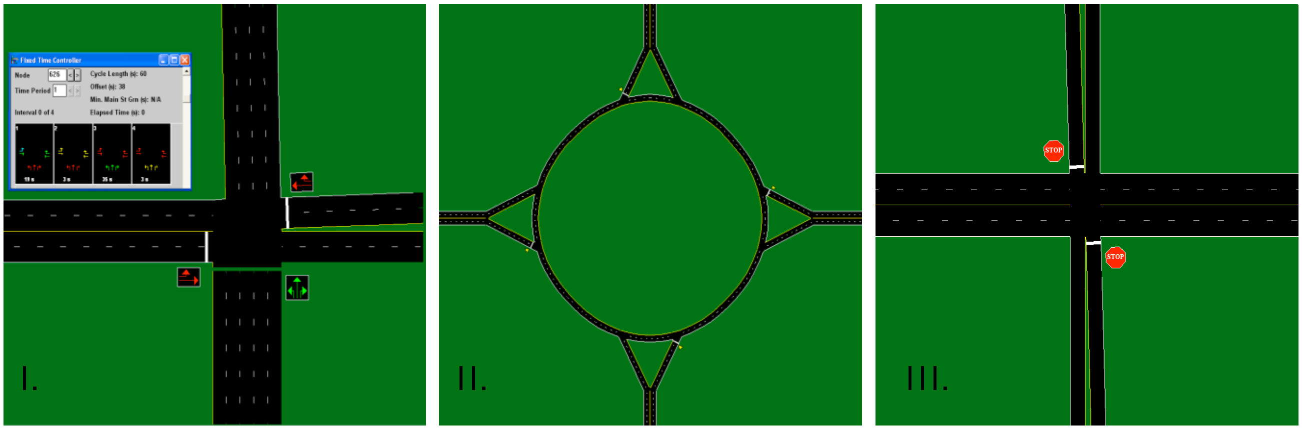
Table 1. Number of required data entries for the conventional method and our aggregate approach for modeling the hypothetical city in Figure 3

| Data needs | Conventional Method | Our Approach |
|---|---|---|
| A. Streets (Links) | | |
| Type of street | 800 | 2 in a map |
| number of lanes | 800 | 2-3 in map |
| length of block | 800 | 2-3 in a map |
| B. Intersections (Nodes) | | |
| Type of node | 400 | 4 in a map |
| Pedestrian counts | 400 | 2-3 |
| C. Origin-Destination Demands | | |
| Origin destination table | 400*400 | 4*4 |
| D. Public Transport | | |
| Frequency of buses | 10 | 10 |
| Stop dwell time | 100 | 4-5 |
| E. System Performance for Validation | | |
| Traffic Counts | 800 * 10 time periods | 10 * 4 time periods |
| Average Speed of Traffic | 800 * 10 time periods | 10 * 4 time periods |

For an idealized city in an orthogonal grid of 20*20 blocks similar to the one in Figure 3 with 800 links, 400 nodes and 10 bus routes with 10 stops each, the required information of the conventional method is huge in comparison with our aggregate approach. Instead of detailed information for each street (length, number of lanes used by traffic, type of street), intersection (signal settings, type, pedestrian quantities), bus route or origin-destination pair, average quantities that can be expressed in a map are sufficient for our analysis.

## 3 Network Construction

To model the street traffic in a city, the first step is to build a model of the road network. This describes the physical infrastructure in the city. A network represents streets as links and intersections as nodes. Each of the links is described by a series of properties such as the width, lane configuration, and the speed of travel when there is no traffic. Nodes where two or more links come together are specified by the intersection control. According to our knowledge of Nairobi there are three different types of intersections as shown in Figure 4: signalized, traffic circles, and un-signalized. Un-signalized intersections can be further specified by having different signage on each approach (Figure 4.III has stop signs on two approaches and unmarked on the others).



Node 626

Time Period 1

Cycle Length (s): 60

Offset (s): 38

Min. Main St Grn (s): N/A

Interval 0 of 4

Elapsed Time (s): 0

19 s

3 s

35 s

3 s

Figure 4. Types of intersections (I. Traffic Signal, II. Traffic Circle, III. Non-signalized)

## 3.1 Conventional Method

A conventional micro-simulation of a city requires a detailed model of the network geometry. In addition to precisely drawing the location of every street in the city, the following properties must be described for each link:

- Length of street segment
- Number of lanes in each direction
- Width of each lane of traffic
- If turning pockets exist and, if so, their exact lengths
- Precise locations of permitted on-street parking

Lane configurations on all approaches of each intersection must also be described in detail. The control at every intersection in the city must be specified to correspond exactly with intersection controls in the actual city. This process is not as complicated where intersections are controlled by stop signs or are unmarked. Describing a signal-controlled intersection, however, requires specific details about the signal design. All intersections need the following:

- Number of lanes from each approach and which lanes are dedicated to which movements
- Signage on each approach (stop, yield, none)
- Number of pedestrians crossing in each direction per hour to model traffic interruptions

For each signalized intersection, the following properties must be assigned to the model:

- Cycle time
- Duration of green and red phases
- Phase offsets relative to surrounding signals

Microscopic simulation models represent movements of individual vehicles which include the influences of driver behavior. Each time a vehicle is moved, its position on the link and its relationship to other vehicles nearby are recalculated, as are its speed, acceleration, and status.

Vehicles are moved according to car-following logic, in response to traffic control devices, and in response to other demands. For example, buses must service passengers at bus stops (stations); therefore, their movements differ from those of private vehicles. Congestion can result in queues that extend throughout the length of a link and block the upstream intersection, thus impeding traffic flow.

## 3.2 Aggregate Method

The conventional micro-simulation methods require enormous amounts of data as demonstrated by Table 1. Our approach still uses a micro-simulation, but it is used only to extract neighborhood-wide, city-scale performance measures. To this end, we only need rough aggregate data.

The streets and intersections still need to be pieced together in our simulation, but each link and node no longer needs to be described individually. Instead, we classify streets and intersections with similar characteristics into categories, and this facilitates the construction of the network. Rather than constructing an exact representation of Nairobi, we construct a simplified abstract city that looks and behaves *like* Nairobi. The simulation will not tell us specifics about traffic on Moi and Haile Selassie Avenues, but it can tell us about general performance of arterial streets.

The street data needed are general averages for the categories, and additional details must be added only for important roads that cannot be categorized (letter-number codes in the list below correspond to data listed in the summary Table 2 in the appendix). Data needs are:

- [A1] Scale map showing geometry of the road network
- [A2] Categorization of streets – a map showing how streets are classified
- [A3] Description of street categories – direction of traffic (1-way or two-way)
- [A4] Number of lanes per direction for a typical street in each category
- [A5] Average block length (the length of the link) for streets in the CBD and periphery. Since the shape of the network is characterized by variations, a scale map of the city streets would be very useful.
- [A6] Free flow speed – the speed of cars where there is very little traffic, excluding stops at intersections.

Intersections must also be described. Again, rather than specifying each intersection individually, the process can be simplified by classifying intersections into a few categories by type. The number of categories should be specified by someone who is more familiar with Nairobi than us, but from our understanding, one classification for each of the intersection controls shown in Figure 4 may be appropriate. Only for intersections so different that they cannot be classified are additional details required. For all intersections, the following data are needed to construct an aggregate model:

- [B1] Categorization of intersections – a map showing how intersections are classified
- [B2] Description of intersection categories – method of control (signal, traffic circle, sign configuration stop/yield/unsigned)
- [B3] Pedestrian counts at intersections by category

Finally, the behavior of traffic on the network needs to be described in general terms. As movements of all vehicles are simulated, they need to behave like vehicles on the streets of Nairobi. For this, two types of data need to be collected by experiment on the streets of Nairobi:

- [A7] Jam spacing of vehicles stopped in queue – this tells us the length of queues caused by stopped traffic.
  *Experiment 1:* For queued traffic stopped on the street, average spacing should be measured by counting the number of vehicles, X, that fit into a length of road, Y. Values should be recorded for a single lane where the queue fills at least 30 meters of road.
- [A8] Capacity of a single lane of traffic – this tells us the maximum rate at which vehicles can discharge from a queue.
  *Experiment 2:* The maximum queue discharge rate can only be measured when vehicles from a queue are released without any downstream blockages. At a signalized intersection where a queue has formed, count the number of vehicles from the queue, X, to enter the intersection during the time, Y, from when the signal turns green to when the last vehicle enters the intersection. Vehicle counts should be collected for at least 20 cycles when there are at least 10 vehicles in the queue that are discharged without obstruction. Vehicles arriving after the queue has cleared should not be counted. Counts should be taken for a single lane at three or four different intersections.

# 4 Origin-Destination Demand Estimation

After the construction of the network, travel demand needs to be put into the simulation for it to run. The demand for travel is structured as an origin-destination (O-D) table which describes the number of trips made between each O-D pair over the course of a day. A traffic assignment model then converts the O-D table into vehicle trips on the street network, and assigns the simulated traffic to the streets in the model.

## 4.1 Conventional Method

In a conventional micro-simulation model, a detailed O-D table must be provided for each time period. For the whole city, this could involve collecting data from hundreds of zones to get travel information at a fine enough level to load the detailed network model. Since a micro-simulation model seeks to describe the traffic on every street and through every intersection with precision, extensive and complete O-D data is required. Collecting this data is an inaccurate, expensive, and time-consuming process that often limits the feasibility of micro-simulation studies.

## 4.2 Aggregate Method

Fortunately, simulation models for aggregate analysis do not require such detail. Since the street network is a simplified approximation of the real city, only general O-D tables are needed. For the simulation to represent Nairobi, we need rough O-D tables for the morning peak, evening peak, and off-peak hours. Rather than specifying hundreds of analysis zones, data at the neighborhood level (such as the 26 zones listed in KIPPRA Report Table 4.1) would be appropriate. The data requirement described in Table 2, section C, will allow us to load the abstract network with representative demands so that aggregate system performance measures can be determined.

## 5 Public Transport Infrastructure and Operations Modeling

Our simulation will include bus operations in addition to car traffic. By including public transport in the simulation, the effects on traffic by buses stopping for passengers are considered. The computer program we will use (CORSIM) bases public transport on the operation of formal bus services with fixed routes and predetermined stops. Bus operations are described by specifying the location of routes, placement of stops and stations, and frequency of service. Each route is described as a listing of links (streets) and nodes (intersections) as well as a listing of the stops along this route where the bus may serve passengers. This is shown in Figure 5. Our understanding is that matatus in Nairobi generally operate on predetermined routes but stop erratically to pick up and drop off passengers. Matatu operations can be approximated by modifying the description of a conventional bus.

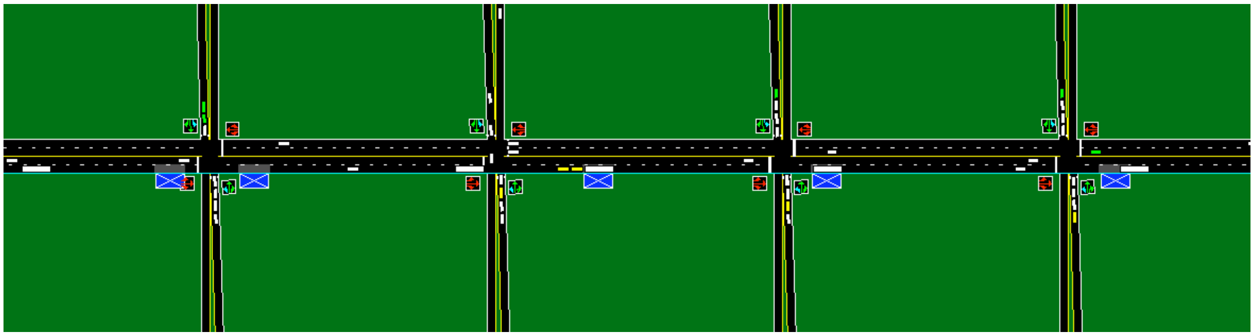


Figure 5. Bus route in a signalized arterial network

### 5.1 Conventional Method

Since a conventional micro-simulation seeks to describe the traffic operations in a city in as much detail as possible, public transport operations in a city must be described precisely. For formal bus services this information is usually available for each route but perhaps tedious to collect:

- Description of routes
- Location of each stop
- Frequency of bus service
- Probability of stopping at each stop
- Dwell time to serve passengers at each stop

City-wide characteristics of the buses should also be described, such as the size of buses used as well the driving speed, acceleration, and deceleration properties. Simulating matatus in this kind of detail is much more difficult, especially if such precision is needed. Our understanding is that matatus stop on demand, so modeling the specific locations of stops is not possible because they can stop anywhere.

### 5.2 Aggregate Method

Simulation of public transport for the aggregate method still requires some details about each route, but the placement of stops and the characteristics of operation can be described based on averages. In CORSIM, matatus can be described by modifying the way conventional buses look and behave. For the matatu system, we need a map of matatu routes and terminals, [D1].

Each matatu route will operate with many potential stops, each with a low probability of actually being used. The frequency of service can be made greater than for conventional scheduled public transport, and the operating characteristics of the vehicles can be described so that matatus in the simulation behave more like Nissan minibuses and less like slow, full-size coaches. Since the interactions between matatus and other vehicles on the road are important in describing the road network performance, the following details are needed for each route:

- [D2] Frequency of matatus in the morning peak, evening peak, and off-peak (matatus per hour)
- [D3] Number of stops made by matatus on a run, and the average passenger load when most full during the morning peak, evening peak, and off-peak
- [D4] Average dwell time to serve passengers at stops – may be the same everywhere or vary by route
- [D5] Average length and width of matatus

Although formal bus services play a much smaller role in serving travel demand in Nairobi, these buses can also be incorporated into the model. The data requirements are similar to those for matatus:

- [D6] Map of bus routes and terminals
- [D7] Frequency of buses in the morning peak, evening peak, and off-peak (buses per hour)
- [D8] Number of stops made by matatus on a run, and the average passenger load when most full during the morning peak, evening peak, and off-peak
- [D9] Average dwell time to serve passengers at stops – may be the same everywhere or vary by route
- [D10] Average length and width of buses

## 6 Simulation

The simulation model is complete when the data described in Sections 3.2, 4.2, and 5.2 have been specified. When the simulation is run, the computer models the movements of cars, matatus, and buses on the streets of the simplified network resembling Nairobi. A visual representation showing vehicle movements and interactions throughout the network can be produced. Where streets meet at intersections, the vehicles interact much as they would in reality. Some must stop to wait for others to progress, a queue forms when an intersection has insufficient capacity to serve the demand. The queue from an overwhelmed traffic circle, for example, may grow to block intersections and delay vehicles in other parts of the network.

The output from the simulation is based on the movements of the simulated vehicles through the streets and intersections of the city. This information is presented in terms of the total distance traveled and the total time spent by all vehicles and passengers on links in the network. These values are the vehicle-hours traveled (VHT), passenger-hours traveled (PHT), vehicle-kilometers traveled (VKT), and passenger-kilometers traveled (PKT). Our simulation will produce values for each link in the network, so the data can be aggregated across the whole city to show overall network performance. One can also convert these performance measures into accessibility measures.

Looking at groups of links can allow for the analysis of a part of the network such as a neighborhood or specific route. The complexities of traffic interactions on the network are a means towards this end. Since the road network is an abstraction of the actual city and not an exact representation of the streets, the specific locations of bottlenecks and congested streets are not as meaningful as the network performance in general.

# 7 Performance Calibration and Validation

The simulation output must be compared with the existing performance of Nairobi's street network to check whether or not the model is representative of the city. There are four types of collectable data against which to check the simulation:

- [E1] Traffic Counts – the number of vehicles passing a point such as an approach to an intersection or a segment of road. High resolution traffic counts are needed, such as over 30 minute periods in the off-peak hours and 15 minute periods during the peak hours. This data is analogous to that presented in KIPPRA Report Table 5.12, but the 12-hour counts do not present enough detail.
- [E2] Average Speed of Traffic – this is the speed of traffic in city neighborhoods and at different times of day including the stops at intersections and the delays due to traffic congestion. Measurements are needed for different times of day since traffic conditions change.
- [E3] Travel Times – the trip times for representative routes across the city. Also needed are measurements for different times of day since traffic conditions change.
- [E4] Commercial Speed of Public Transport – the average speed of matatus and buses including stops for passengers. Measurements are needed for different times of day since traffic conditions change.

All of these values can be derived from the simulation outputs as well.

We calibrate the model by slightly adjusting driver behavior data until the computed values from simulation of the abstract city are similar to the measurements from the real city. This agreement indicates that the model and simulation are representative of the aggregate performance of the city and provide a description of Nairobi's existing conditions.

# 8 Purpose of Simulation

The purpose of simulating Nairobi is to use a model of the city as it is currently and to predict how changes in demand or traffic control will affect the transportation system performance. For each mode, the measures of VHT, PHT, VKT, and PKT can be used to compute measures of effectiveness that reveal important properties of the system performance. These outputs are aggregated geographically and therefore represent the performance of the transportation network for the whole city or a section of interest, such as the central business district. These outputs can be used to calculate indicators of system performance. One of the most important is the accessibility provided by the transportation system. Accessibility describes the number of jobs and opportunities that people can reach by car and public transport in a given budget of time or money. Other indicators can also be calculated.

# 9 Additional Information

A simulation model can be built with the input described in Sections 1 through 6, but additional information would be helpful to improve the quality of analysis. The provision of parking is closely related to the level of car use. An inventory of the amount of parking provided, especially in the central business district, can be used as a check against the number of simulated trips to see if the demands in the model make sense. The following information would be useful in understanding parking provision in Nairobi and implications for car use:

- [F1] Map of parking in Nairobi especially in the central business district
- [F2] Number of parking spaces provided off-street (spaces in parking lots and garages) and on-street (spaces along road edge or median).
- [F3] Availability of parking – this can be a rough or even qualitative description of how much existing parking spaces are used such as an estimated percentage of spaces occupied during the most crowded time of the day. This may be especially important if drivers must spend a lot of time driving around in search of a parking space, thus contributing traffic to the streets.

From a more general perspective, we would like this analysis to address the most pressing traffic problems in Nairobi today. There are some aspects of the city's transportation performance that may not be readily apparent from looking at a cross-section of traffic data. A description of the most urgent traffic concerns, [F4], from the perspective of a Nairobi resident in terms of problematic streets, intersections, neighborhoods, types of intersection control, or classes of vehicles would help direct our focus. The simulation we will be making will not represent Nairobi in exact detail, but to get the most meaningful results from this work, we need input from people who know the city and can guide our attention to the transportation problems that need attention.

## Appendix: Data Requirements Summary

The data needs listed below are the minimum requirements to build a simulation model as described in the report. Where more detailed data is available, it is welcomed, but averages can suffice. Based on our limited knowledge of Nairobi, we think streets and intersections may be broadly classified into 3 or 4 categories. You are encouraged to change the number of categories to best describe the city. Where the term "Category X" is used, data is requested for each category of streets and intersections.

Table 2. Comprehensive list of required data

| Data Field | Available?<br>(Yes, if you can fill the blanks) |
|---|---|
| A. Streets (Links) *Section 3.2* | |
| ☐ 1. *Scale Map of Nairobi Streets* including the CBD and periphery | |
| ☐ 2. *Map of streets* showing which streets fall into each category (Figure 6): in detail (all streets) in city center; major roads in city periphery | |
| ☐ 3. *Description of each street category:*<br>Category X streets serve traffic in 1 or 2 directions? _____ | |
| ☐ 4. *Average number of lanes* for streets in each category:<br>Category X streets have an average of _____ lanes for moving traffic in each direction. Lanes used for parking should not be counted.<br>Notable exceptions – provide more detailed lane information for important roads that do not fit into a general category.<br>[Analogous to KIPPRA Report Table 5.11] | |
| ☐ 5. *Average length of blocks* for streets in each category/part of city:<br>Category X streets average _____ meters between intersections in the CBD, and _____ meters between intersections in the city's periphery.<br>Notable exceptions – provide more detailed block length information where necessary. | |
| ☐ 6. *Free flow speed:*<br>Without traffic congestion, vehicles on Category X streets move at an average speed of _____ kilometers per hour between intersections. | |
| ☐ 7. *Traffic Jam Spacing:*<br>When traffic is stopped in queue, _____ vehicles fit in one lane in 30 m.<br>See detailed description for data collection in Section 1.2. | |
| ☐ 8. *Lane capacity:*<br>When queued traffic at a traffic signal is permitted to discharge freely into an intersection, up to _____ vehicles per minute can be carried by a single lane.<br>See detailed description for data collection in Section 1.2. | |

| | |
|---|---|
| **B. Intersections (Nodes)** *Section 3.2* | |
| ☐ 1. *Map of intersections* showing of intersections by category (Figure 6):<br>in detail in city center; where streets from map A1 intersect in periphery | |
| ☐ 2. *Description of each intersection category:*<br>Category 1 intersections are controlled by traffic signals.<br>Typical cycle time is _____ seconds long.<br>Typical green phases are _____ seconds, and red phases are _____ sec.<br>If there is a difference between signals serving intersections of 2 major streets and signals for intersections of a major and a minor street, please provide this information for both types. | |
| Category 2 intersections are controlled by traffic circles<br>Traffic circles are typically _____ meters in diameter.<br>Traffic circles typically have _____ lanes.<br>Notable exceptions – large traffic circles behave differently than small ones, so provide details for unusually large or small traffic circles. | |
| Category 3, 4, etc. intersections are controlled by _________ (e.g. stop signs for all approaches, stop signs on minor approaches only, or completely unmarked). | |
| Notable exceptions – provide detailed description of important intersections that cannot be categorized. | |
| ☐ 3. *Pedestrian counts crossing streets at intersections* (rough averages):<br>Category X intersections have _____ pedestrians crossing each direction in the average peak hour in the CBD and _____ in the periphery | |
| **C. Origin-Destination Demands** *Section 4.2* | |
| ☐ 1. *Map of origin-destination zones showing locations on a street map*<br>[Zones listed in KIPPRA Report Table 4.1 are sufficient] | |
| ☐ 2. *Origin-destination flows by time of day:*<br>For each O-D pair in the morning peak, on average there are _____ people per hour traveling by private car, _____ people per hour traveling by matatu, and _____ people per hour traveling by bus. | |
| For each O-D pair in the evening peak, on average there are _____ people per hour traveling by private car, _____ people per hour traveling by matatu, and _____ people per hour traveling by bus. | |
| For each O-D pair in the off-peak, on average there are _____ people per hour traveling by private car, _____ people per hour traveling by matatu, and _____ people per hour traveling by bus.<br>[Data collected for KIPPRA Report Section 5 may hold this information] | |
| **D. Public Transport** *Section 5.2* | |
| ☐ 1. *Map of matatu routes and terminals:*<br>Show locations of terminals where matatus wait for passengers in the CBD and periphery on a street map.<br>Show matatu routes (at least the most heavily served routes) and specifically which streets in the CBD they use. | |

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| ☐ 2. *Matatu frequencies on each route by time of day:*<br>For each matatu route in the morning peak, on average there are _____ matatus per hour into the city and _____ matatus per hour heading out. | |
| For each matatu route in the evening peak, on average there are _____ matatus per hour into the city and _____ matatus per hour heading out. | |
| For each matatu route in the off-peak, on average there are _____ matatus per hour into the city and _____ matatus per hour heading out. | |
| ☐ 3. *Matatu loads and stops by time of day and route:*<br>For each route, during the morning peak, matatus carry an average of ______ onboard passengers when most full and make _____ stops headed into the city, and _____ headed out. | |
| For each route, during the evening peak, matatus carry an average of ______ onboard passengers when most full and make _____ stops headed into the city, and _____ headed out. | |
| For each route, during the off-peak, matatus carry an average of ______ onboard passengers when most full and make _____ stops headed into the city, and _____ headed out. | |
| ☐ 4. *Matatu stop dwell time:*<br>The average duration of a matatu stop to pick-up or drop off passengers in traffic is _____ seconds. Please specify if different across routes. | |
| ☐ 5. *Matatu size on each route:*<br>For each matatu route, the average matatu is _____ meters long and _____ meters wide. | |
| ☐ 6. *Map of formal bus routes and terminals:*<br>Show locations of terminals where buses wait for passengers in the CBD and periphery relative to the street network.<br>Show bus routes and specifically which streets in the CBD they use. | |
| ☐ 7. *Bus frequencies on each route by time of day:*<br>For each bus route in the morning peak, on average there are _____ buses per hour into the city and _____ buses per hour heading out. | |
| For each bus route in the evening peak, on average there are _____ buses per hour into the city and _____ buses per hour heading out. | |
| For each bus route in the off-peak, on average there are _____ buses per hour into the city and _____ buses per hour heading out. | |
| ☐ 8. *Bus loads and stops by time of day:*<br>For each route, during the morning peak, matatus carry an average of ______ onboard passengers when most full and make _____ stops headed into the city, and _____ headed out. | |
| For each route, during the evening peak, matatus carry an average of ______ onboard passengers when most full and make _____ stops headed into the city, and _____ headed out. | |
| For each route, during the off-peak, matatus carry an average of ______ onboard passengers when most full and make _____ stops headed into the city, and _____ headed out. | |

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| ☐ 9. *Bus stop dwell time:*<br>The average duration of a bus stop to pick-up or drop off passengers in traffic is _____ seconds.<br>While buses stop for passengers, do they block traffic (Y/N)? _____ | |
| ☐ 10. *Bus size on each route:*<br>For each bus route, the average bus is _____ meters long and _____ meters wide. | |
| **E. System Performance for Validation** *Section 7* | |
| ☐ 1. *Traffic Counts* for representative streets and intersections by time of day<br>For a representative Category X intersection during peak hours, 15 minute counts of cars, matatus, and buses for each approach. | |
| For a representative Category X intersection during off-peak hours, 30 minute counts of cars, matatus, and buses for each approach.<br>[Analogous to KIPPRA Report Table 5.12, but disaggregated] | |
| ☐ 2. *Average Speed of Traffic:*<br>For a representative Category X street, during the morning peak, cars move an average of at _____ km per hour including stops. | |
| For a representative Category X street, during the evening peak, cars move an average of at _____ km per hour including stops. | |
| For a representative Category X street, during the off-peak, cars move an average of at _____ km per hour including stops. | |
| ☐ 3. *Travel Time:*<br>For 3 or 4 representative trips across the city (2-10 km) by car, the travel time is _____ minutes in the morning peak, _____ minutes in the evening peak, and _____ minutes in the off-peak. | |
| ☐ 4. *Commercial Speed of Public Transport:*<br>Over the length of a route, matatus travel at an average speed (including stops) of _____ km per hour during peak hours, and _____ kph during off-peak hours. | |
| Over the length of a route, buses travel at an average speed (including stops) of _____ km per hour during peak hours, and _____ kph during off-peak hours | |
| **F. Additional Information** *Section 9* | |
| ☐ 1. *Map of parking* showing where parking is provided on the street and roughly where major off-street parking lots or garages are located | |
| ☐ 2. *Number of spaces provided* especially in the central business district:<br>In the CBD, there are approximately _____ parking spaces in off-street parking lots and garages and _____ spaces for cars on-street. | |
| ☐ 3. *Availability of parking* either of the following way:<br>During the busiest part of the day, approximately _____ percent of the parking spaces in the CBD are occupied.<br>During the day, it typically takes a driver _____ minutes to find a space. | |
| ☐ 4. *Pressing Traffic Problems:*<br>Describe most pressing transportation concerns in Nairobi. This may be particularly problematic intersections, neighborhoods, traffic control devices, types of vehicles, etc. This will help direct our focus. | |

Figure 6, below, shows an example of a street map annotated to show classification of streets and intersections. The assigned categories below are not accurate, because we do not yet know the details of Nairobi's road network, but this is an illustration of the type of map that would be useful in fulfilling the data requirements listed in A1 and B1.

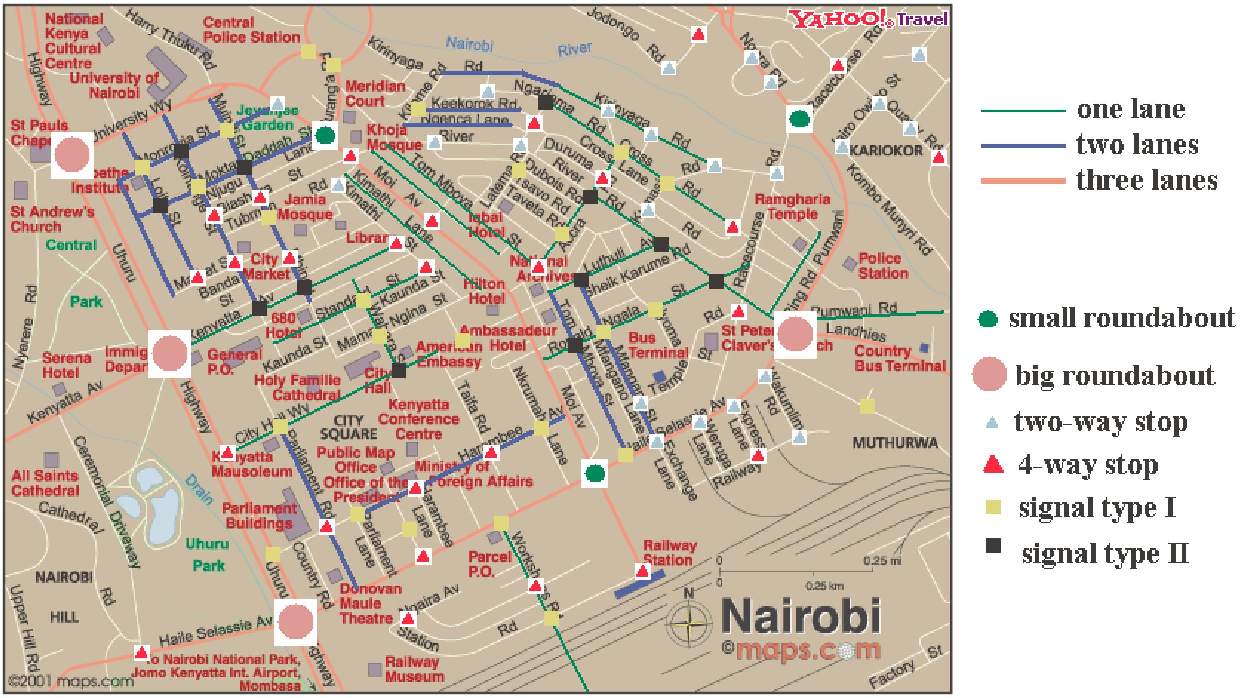

Figure 6. Example of required map for Nairobi Central Business District

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