

# Evaluating the Impact of Road Traffic Congestion Mitigation Measures in Nairobi Metropolitan Region

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**THE KENYA INSTITUTE FOR PUBLIC POLICY  
RESEARCH AND ANALYSIS (KIPPRA)**

**YOUNG PROFESSIONALS (YPs) TRAINING  
PROGRAMME**

# **Evaluating the Impact of Road Traffic Congestion Mitigation Measures in Nairobi Metropolitan Region**

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*Infrastructure and Economic Services Division*  
Kenya Institute for Public Policy  
Research and Analysis

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## **Abstract**

*Traffic congestion is a major problem in many cities around the world, including the Nairobi Metropolitan Region (NMR). Given the high economic, social and environmental costs incurred on account of road traffic congestion, the Government of Kenya as well as other actors have planned and implemented various strategies in an effort to mitigate these negative effects. This study evaluate the effectiveness of road traffic congestion mitigation measures in the NMR, aiming to establish strategic options that could be used to mitigate the problem of road traffic congestion.*

*The methodology used in this research was based on the Four Step Model (FSM) of travel demand forecasting. A FSM of travel demand in NMR was built using Geographical Information Systems (GIS) and this was followed by simulation of the effects of implementing different traffic congestion mitigation measures. Results from data analysis reveal that the problem of traffic congestion will be significantly worse by the year 2030, if no measures are taken to address it. Traffic congestion in NMR is influenced by both demand and supply side factors. It also emerges that majority of traffic flows were concentrated in the central area of Nairobi city.*

*The results of the simulations reveal that increasing the capacity of roads has the greatest effect on reducing congestion. Implementation of the modal shift strategies has the second best effect on reducing congestion. The third best mitigation strategy is building the bypass roads and missing links, while implementation of multi-centric development of the NMR is fourth. A combination of all mitigation measures yield a significant reduction in road traffic congestion, representing a 70 per cent decrease. It is observed that traffic flows on the major roads in Nairobi city follow a temporal pattern of high flows that coincide with hours in which most work trips and home trips are executed.*

*The main conclusion from the foregoing analysis is that both demand side and supply side measures have significant effect on reducing road traffic congestion. The current practice in regard to traffic congestion mitigation in the NMR has placed more emphasis on the supply side, while the demand side and time-oriented strategies have been less prominent. It is recommended that traffic congestion mitigation measures be implemented in an integrated demand and supply side strategy in the NMR. The mitigation measures should vary depending*

*on the prevailing traffic dynamics of a particular road or traffic zone. Further, it is recommended that policies focus on providing reliable and predictable travel times as well as efficient travel speeds. Finally, the amount of automobile travel generated, irrespective of roadway capacity, should be adopted as an indicator to measure transport system performance in order to capture the demand side.*

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## **Abbreviations and Acronyms**

AfDB	African Development Bank
AON	All or Nothing
BMA	Bangkok Metropolitan Authority
BRT	Bus Rapid Transit
CAGR	Compound Annual Growth Rate
CBD	Central Business District
CCN	City Council of Nairobi
CCS	Congestion Charging Scheme
CES	Consulting Engineers Services (PTY) India
CO	Carbon Monoxide
CO <sub>2</sub>	Carbon Dioxide
CSUD	Centre for Sustainable Urban Development
CTR	Commuter Trip Reduction
DBF	Data Base Format
DSRS	Downtown Space Reservation System
ECMT	European Conference of Transport Ministers
EDS	Electronic Violation Detection Systems
FSM	Four Step Model
GDP	Gross Domestic Product
GHG	Green House Gas
GIS	Geographic Information System
GoK	Government of Kenya
GRP	Gross Regional Product
HOV	High Occupancy Vehicle
IBM	International Business Machines
ITS	Intelligent Transport System
JICA	Japan International Cooperation Agency
KeNHA	Kenya National Highways Authority
KES	Kenya Shillings
KIPPRA	Kenya Institute for Public Policy Research and Analysis

KNBS	Kenya National Bureau of Statistics
KURA	Kenya Urban Roads Authority
LOS	Level of Service
LRT	Light Rail Transit
MoNMD	Ministry of Nairobi Metropolitan Development
MoT	Ministry of Transport
MRTS	Mass Rapid Transit System
MTL	Mean Trip Length
NGO	Non-Governmental Organization
NMR	Nairobi Metropolitan Region
NMT	Non-Motorized Transport
NOx	Nitrogen Oxide
NUTRANS	Nairobi Urban Transport Study
O-D	Origin -Destination
OECD	Organisation for Economic Cooperation and Development
PCD	Pollution Control Department
PCTR	Per Capita Trip Rate
PCU	Passenger Car Units Equivalent
PM10	Particulate matter with an aerodynamic diameter of 10 micro metres or less
TAZ	Traffic Analysis Zone
TCC	Traffic Control Centre
UGB	Urban Growth Boundary
USD	United States Dollar
USA	United States of America
V/C	Volume to Capacity
VMT	Vehicle Miles Travelled
VOC	Volatile Organic Compounds
VQS	Vehicle Quota Scheme

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## Table of Contents

<i>Abstract</i> .....	<i>iii</i>
<i>Abbreviations and Acronyms</i> .....	<i>v</i>
1. Introduction .....	1
1.1 Context .....	1
1.2 Problem Statement.....	2
1.3 Objectives and Research Questions .....	3
1.4 Justification and Relevance.....	4
2. Overview: Urban Transport System in Nairobi Metropolitan Region.....	6
2.1 Nairobi Metropolitan Region .....	6
2.2 Transport in Nairobi Metropolitan Region .....	7
2.3 Population Dynamics .....	7
2.4 Land Use.....	8
2.5 Road Network.....	8
2.6 Vehicle Ownership .....	9
2.7 Public Transport System in Nairobi .....	9
2.8 Travel Demand and Mobility Trends .....	10
2.9 Transport Policy, Legal and Institutional Framework..	13
2.10 Traffic Congestion in Nairobi.....	13
2.11 Traffic Congestion Mitigation in Nairobi .....	16
3. Literature Review: Road Traffic Congestion .....	18
3.1 Understanding Traffic Congestion .....	18
3.2 Causes of Traffic Congestion.....	20
3.3 Effects of Traffic Congestion .....	22
3.4 Traffic Congestion Mitigation .....	27
3.5 Empirical Studies on Traffic Congestion Mitigation .....	31
3.6 What Is The Solution?.....	37
4. Analytical and Methodological Framework.....	38
4.1 Analytical Framework .....	38
4.2 Conceptual Framework.....	40
4.3 Methodological Framework.....	42
5. Data Analysis.....	45
5.1 Research Question 1: Travel Demand Model.....	45
5.2 Measuring Traffic Congestion-V/C Ratio .....	48



5.3 Simulation of the Effects of Traffic Congestion Mitigation Measures .....	48
6. Results and Discussion .....	53
6.1 Travel Demand .....	53
6.2 Measuring Traffic Congestion.....	55
6.3 Effects of Traffic Congestion Mitigation Measures .....	57
7. Conclusion and Recommendations .....	60
7.1 Limitations.....	60
7.2 Conclusion .....	60
7.3 Recommendations.....	62
References .....	65
Appendix .....	73

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# 1. Introduction

## 1.1 Context

Road traffic congestion is essentially a relative phenomenon that is linked to the difference between the roadway system performance that users expect and how the system actually performs. It entails the impedance vehicles impose on each other due to the speed-flow relationship in conditions where the use of a transport system approaches capacity (Organization for Economic Cooperation and Development/European Conference of Transport Ministers, 2007).

Some of the main causes of traffic congestion can be attributed to a combination of factors such as high travel demand, the nature of travel behaviour patterns, limited choice in mode of transport, uncoordinated spatial distribution of land uses and activities, increased vehicle ownership, bad driving habits, poor road conditions, increased urban population, inefficient road design, poor traffic management systems among others. Negative impacts of traffic congestion can be categorized into social, economic, and environmental. Traffic congestion leads to loss in productive work hours for labour, reduced access to factors of production and consumption, increased costs of production, reduced city competitiveness, adverse impacts on quality of life, health and welfare and environmental pollution.

Traffic congestion is a major problem in many cities around the world. In the Nairobi Metropolitan Region (NMR), traffic congestion has become a common phenomenon in the transport network and it is estimated to have an economic cost of approximately Ksh 1.9 billion annually on account of cost of time spent on travel due to congestion.<sup>1</sup> The Government of Kenya and City Council of Nairobi (CCN) have planned and implemented various strategies in an effort to mitigate road traffic congestion. Some of the recent efforts include road infrastructure expansion aimed at increasing capacity; establishment of the traffic decongestion programme by the Ministry of Nairobi Metropolitan Development (MoNMD); undertaking feasibility studies and planning on alternative modes of transport such as mass rapid transit by the Ministry of Transport (MoT); and increasing vehicle parking fees (CCN). The private sector, civil society, non-governmental organizations (NGOs) and international development partners have

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<sup>1</sup>Based on a presentation by Edwins Mukabanah, available from [http://www.kenyabus.net/uploads/downloads/Public\\_Transport\\_Presentation\\_-\\_Nairobi\\_Metropolitan.pdf](http://www.kenyabus.net/uploads/downloads/Public_Transport_Presentation_-_Nairobi_Metropolitan.pdf) [accessed on 27 January 2011].

also been engaged in campaigning for alternative measures for traffic congestion mitigation such as promotion of non-motorized modes of transport. Similarly, global examples of best practices in traffic congestion mitigation for Kenya are also available.

This study aims to analyze the impact of the proposed traffic congestion mitigation measures by evaluating their quantitative effect on the road traffic volume-to-capacity (V/C) ratio. Various traffic congestion mitigation measures will be explored with the aim of establishing the best mix of strategies. This study provides policy guidance on strategic, cost effectiveness and efficient solutions to traffic congestion. The audience of this study will gain a deeper understanding of traffic congestion as a phenomenon on urban roads.

## **1.2 Problem Statement**

The objective of any transport system is to facilitate the movement of people, goods and services as efficiently as possible from origins to destinations that are spatially separated. Borrowing from Pisarski (1999), it is noted that the goal of transportation is to reduce the effects of distance as an inhibiting force in our society's ability to realize its economic and social aspirations - to 'destroy' distance as a factor in meeting society's needs. Furthermore, transportation is all about reducing the time and cost penalties of distance on our economic and social interactions. However, the problem arises when the movement of goods and services through the transport network increases to a level that it exceeds the design capacity of the networks. This means that the demand for travel in form of trips along the network outstrips the supply of the transport system to serve this demand. The outcome is what we refer to as traffic congestion, which is a condition on road networks that occur as use increases, and is characterized by slower speeds, longer trip times and increased vehicular queuing.

The Government of Kenya and other non-state agencies are keen on finding solutions to traffic congestion. It has been noted earlier that various strategies have been put in place to tackle road traffic congestion. Theory and global experiences also offer a variety of solutions to mitigation of road traffic congestion. Each of the solutions has its merits and demerits; more so, the suggested solutions may not be effective if implemented separately, hence requiring joint application. Furthermore, the solutions may be context/country-specific, meaning

that one solution may work in some countries but may be difficult to implement in another. Policy makers are thus faced with the problem of selecting the best “mix/cocktail” of solutions to mitigate road traffic congestion.

Fully eradicating roadway congestion is neither an affordable nor a feasible goal in economically dynamic urban areas. Some of the traffic congestion mitigation measures such as road infrastructure expansion are very expensive and have wide ranging economic, social and environmental effects. Therefore, any traffic congestion mitigation measure is only justifiable when the marginal costs of congestion to society exceed those for reduction. This, therefore, requires that careful planning, estimation and forecasting is undertaken before any mitigation measure is implemented.

Each of the proposed road traffic congestion mitigation measures has an effect on traffic congestion, but given the limited resources available to transport planners, strategic selection of the best alternative is necessary, thus finding a sustainable solution is an economic problem.

### **1.3 Objectives and Research Questions**

This study’s objective is to evaluate the effectiveness of alternative traffic congestion mitigation measures in Nairobi. The specific objectives are to:

- (i) Model travel demand in Nairobi
- (ii) Establish the level of road traffic congestion in Nairobi
- (iii) Measure the effect of different mitigation measures on traffic congestion
- (iv) Make policy recommendations for traffic congestion mitigation

The pertinent research questions are:

- (i) How many trips are generated in Nairobi and where to? What mode of transport is used and on what routes?
- (ii) What is the level of traffic congestion, and what is the spatial distribution of congestion in the transport network?
- (iii) Which mitigation measures have been proposed to address traffic congestion, and what is the quantified effect of the

mitigation measures?

- (iv) What are the policy implications of traffic congestion? Which strategic mitigation measures can be recommended to address traffic congestion?

#### **1.4 Justification and Relevance**

In Kenya, various policies and plans have been put forth that have direct implications on the transport sector. These strategies are geared towards making Kenya “a globally competitive and prosperous country with a high quality of life to all citizens in a clean and secure environment”, as envisaged in Vision 2030. The Integrated National Transport Policy aims at achieving “a world-class integrated transport system responsive to the needs of people and industry”. The mission of this policy is “to develop, operate and maintain an efficient, cost effective, reliable, safe, secure and integrated transport system and link transport policy with other sectors in order to achieve national and regional development aspirations in a socially, economically and environmentally sustainable manner”. The Nairobi Metro 2030 Strategy envisions a “world class African metropolis.” Its mission is to build a robust, internationally competitive, dynamic and inclusive economy; develop world class infrastructure to support development; and enhance linkages and accessibility to national, regional and global contexts.

Traffic congestion is a threat to the attainment of Vision 2030. It is also one of the major contemporary problems in the NMR. The manner in which traffic congestion will be addressed is crucial to the future development of the NMR. This research is therefore important because it will provide insight on how to effectively mitigate traffic congestion and thus secure the NMRs vision.

Given the traffic challenges in the NMR, answers to the following questions are necessary: what is the “best mix” of road traffic congestion mitigation measures for Nairobi? Will the traffic congestion mitigation measures reduce road traffic congestion? By how much will the traffic congestion be reduced? And are the mitigation measures sustainable and effective now and into the future (2030)?

The NMR is currently under reconstruction in terms of transport infrastructure development. This study is timely because it will evaluate the impacts of some of these infrastructure projects under different

scenarios and provide policy recommendations based on evidence.

Based on the common wisdom ‘prevention is better than cure’, this study interrogates the phenomenon of traffic congestion, with the aim of establishing its causes and effects in NMR. A good understanding of the causes and effects will provide sufficient background for implementation of “congestion prevention measures” to address the causes and ‘curative’ or mitigation measures that address the effects.

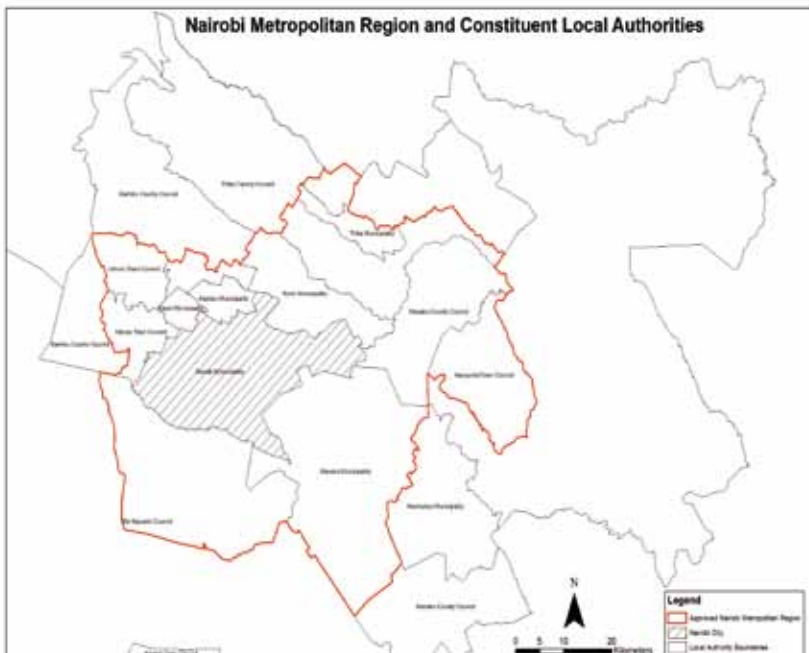
This study also demonstrates the application of innovative techniques, methodology and instruments for travel demand modelling. In particular, it seeks to highlight the utility of Geographical Information Systems (GIS) and Spatial Planning Decision Support Systems (SPDSS) in policy research and analysis.

## 2. Overview: Urban Transport System in Nairobi Metropolitan Region

### 2.1 Nairobi Metropolitan Region

Nairobi has over the years witnessed growth in terms of spatial extent expanding from its original core city and is now recognized as a metropolitan region consisting of 15 local authorities. According to the Nairobi Metro 2030 Strategy, the NMR encompasses the following fifteen independent local authorities: City Council of Nairobi, Municipal Council of Kiambu, Municipal Council of Limuru, Municipal Council of Machakos, Municipal Council of Mavoko, Municipal Council of Ruiru, Municipal Council of Thika, Town Council of Kajiado, Town Council of Karuri, Town Council of Kikuyu, Town Council of Tala/Kangundo, County Council of Kiambu, County Council of Masaku, County Council of Ol Kejuado, and County Council of Thika. In terms of size, the approved NMR covers an area of 4,438 Km<sup>2</sup>, of which Nairobi city covers 695Km<sup>2</sup>. Figure 2.1 shows the spatial context of NMR, Nairobi City and the constituent municipalities.

**Figure 2.1: Nairobi Metropolitan Region and constituent local authorities**



## 2.2 Transport in Nairobi Metropolitan Region

There have been three recent holistic transport studies that fall within the travel demand framework (Table 2.1). These studies were comprehensive and able to capture detailed information on urban transport in NMR.

## 2.3 Population Dynamics

Nairobi, the capital city of Kenya, has witnessed growth in population over the years. According to the Kenya National Bureau of Statistics (KNBS) 2009 census, Nairobi has a total population of 3,138, 369. It is estimated that under the business as usual scenario, NMR will have a population of 8 million by the year 2012 and 14 million by the year 2030 (Government of Kenya, 2008).

Aligula *et al.* (2005) note that Nairobi's urban transport system has been shaped by population pressure, the urban structure and the general transport system. They also note that many of the current transport problems in Nairobi are attributable to the high population growth rate, low vehicle capacities, high energy costs and far location of high density residential areas, among others.

**Table 2.1: Recent transport studies undertaken in the Nairobi metropolitan region**

Year	Study title	Client/Authorizing agency	Consultant/Study team
2010	Feasibility Study for Mass Rapid Transit Systems (MRTS) in Nairobi Metropolitan Region	Government of Kenya, Ministry of Transport	M/S Consulting Engineering Services (India); Pvt. Ltd, New Delhi; and M/S APEC Consultants of Nairobi
2006	Study on Master Plan for Urban Transport in the Nairobi Metropolitan Area (NUTRANS)	Government of Kenya, Ministry of Roads/ Japanese International Cooperation Agency (JICA)	Katahira and Engineers International / RECS International
2005	Urban Public Transport Patterns in Kenya: A Case Study of Nairobi City	Kenya Institute for Public Policy Research and Analysis (KIPPRA)	Dr. Eric M. Aligula; Zachary Abiero-Gariy; John Mutua; Fredrick Owegi; Charles Osengo; Reuben Olela



## **2.4 Land Use**

According to a study by Aligula *et al.* (2005), the land use in Nairobi is characterized by a strong CBD, which has been expanding over the years, and a radial road network for commuting between work and residential areas. Majority of the land use changes in Nairobi have been from residential to commercial, and mixed land uses. Former residential areas have been converted to commercial use and a concept of retail street within previously enclosed shops has emerged within the CBD. Areas that did not change in land use have instead witnessed increased densification through construction of high-rise buildings for residential and commercial purposes. In terms of the conversion rate for the different land use changes, residential to commercial land use changes account for 47.7 per cent, 39.6 per cent, 40.6 per cent and 21.3 per cent of the approved land use changes in 2000, 2001, 2002, and 2003, respectively. With reference to the transportation system, land use changes have also occurred along the main transport corridors within the city, with commercial land uses creating more demand on the deteriorating transport network in Nairobi.

## **2.5 Road Network**

The importance of the road network is captured by the National Integrated Transport Policy 2009, which observes that road transport carries over 93 per cent of all freight and passenger traffic in the country. Nairobi has approximately 1,214km of roads, of which 972km are paved roads and 178km are earth and gravel roads. The classified road network is 265km. The classes comprise primary roads, distributor roads and access roads. In addition to the road carriageway, other components of the road network include termini, parking facilities and bus stops. Most road infrastructure network within the city falls along the ridges/raised points and tend to avoid swampy areas, deep valleys and other difficult terrains (Aligula *et al.*, 2005).

Based on history, the plan of Nairobi City, during the colonial period, segregated the population into European, Asian and African zones. This segregated character of the city has continued into the post-independence era, with the former European zones and now higher income areas receiving better infrastructure and mobility for the private car, while the former non-European areas and now low income areas have poor provision of road infrastructure (Aligula *et al.*, 2005).

## 2.6 Vehicle Ownership

It is estimated that out of the approximately 900,000 registered motor vehicles in Kenya, 67 per cent (603,000) are located in the NMR (Katahira and Engineers, 2006; and KNBS, 2009). Ownership of motor vehicles has been increasing over the years at a rate of approximately 5.58 per cent (Kenya National Bureau of Statistics, 2009). Motor cars have increased at a faster rate of 7 per cent than buses and mini-buses (5%), which could imply that personal vehicles are becoming more popular as a mode of transport in the country and especially in NMR (Consulting Engineers Services and APEC, 2010). Approximately 15-23 per cent of households own a vehicle in Nairobi (Aligula *et al.*, 2005; Katahira and Engineers International, 2006). The Nairobi Metropolitan Growth Strategy of 1973 estimated that household car ownership in Nairobi was 0.36 vehicles per household, while the motorization rate was estimated at 23 vehicles per 1,000 people (Oumarou and Kulemeka, 2007). The World Bank puts the national figure at 21 vehicles per 1,000 people in 2007. The growth in ownership of motor vehicles can be explained by the trends of Gross Domestic Product (GDP) in the country. It is noted that an increase in national and per capita GDP contributes greatly to motorization or private car ownership, leading to greater demand for highway expansion and energy consumption.

## 2.7 Public Transport System in Nairobi

The public transport system in Nairobi is composed of buses, *matatus* (privately owned mini buses) and intermediate public transport (taxi, *tuk tuk*, motorcycle *boda boda* and bicycle taxis). In terms of the bus system, a study by CES and APEC (2010) revealed that there are 8 bus companies that operate 800 buses in the NMR on about 67 routes and are estimated to carry about 0.35 to 0.40 million passengers per day.

*Matatus* play a key role in providing mobility for majority of Nairobi residents. It is estimated that *matatus* carry about 33 per cent of the urban commuter traffic, which amounts to about 3 million passengers per day (CES and APEC). *Matatus* are the main mode of transport for 80 per cent of the public transport users (Katahira and Engineers International, 2006). However, the *matatu* system is primarily an informal system that fails to meet the basic criteria of conventional public transport; that is, affordability, reliability, safety, security, punctuality and coordination with other modes of transport. This has largely been

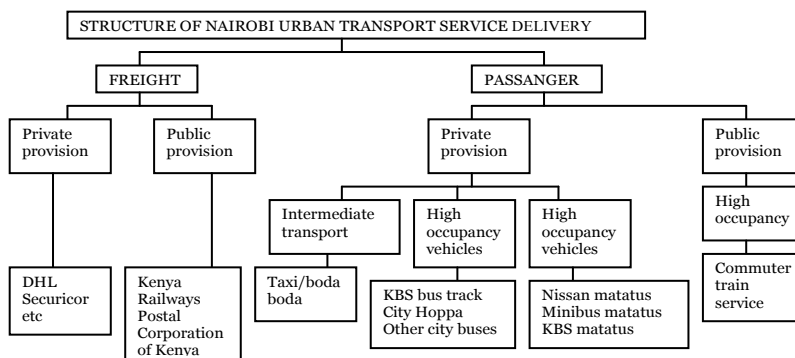
attributed to the deregulated nature of the system and the profit seeking behaviour of operators, who have no social obligation. This has led to some authors regarding the *matatu* system as an informal para-transit mode (Gonzales *et al.*, 2009; and Graeff, 2009), and as such, Nairobi does not have a conventional public transport system.

The intermediate public transport system comprising taxis, *tuk tuks*, and motorcycle and bicycle *boda bodas* not only provides a complementary and supplementary role to buses and *matatus*, but also provides the only mode of mobility for some residents. There are about 4,000 taxis; 200 *tuk tuks*; 50,000 motorcycles, and 1,500 bicycle taxis in operation in NMR (CES and APEC, 2010). Figure 2.2 summarises the structure of the urban transport system service delivery in Nairobi.

## 2.8 Travel Demand and Mobility Trends

Based on the study by Aligula *et al.* (2005), the estimated average household size in Nairobi is 3.54 persons per household. Approximately 16.5 per cent of total household expenditure was for transport. The study observed that about 67 per cent of the respondents spent more than 10 per cent of their earnings on transport. In 2006, the trip rate in Nairobi was estimated at 2.25 trips per person per day (Aligula *et al.*, 2005; Katahira and Engineers International, 2006), while in 1973 each household produced 6.85 trips. The study by CES and APEC (2010) used a Per Capita Trip Rate (PCTR) of 1.27 trips per person for NMR and estimated that there were 4.66 million passenger trips taking place through private cars, buses and *matatus* per day. According to Oumarou and Kulemeka (2007), the demand for public

**Figure 2.2: Structure of the urban transport system in Nairobi**



Source: Adopted from Aligula *et al.* (2005) and CES and APEC (2010)

transport was 1.8 million daily trips in 2007 and was projected to rise to 2.9 million daily trips by 2025. A categorization of trips according to purpose revealed that home to work trips comprised the majority (25%) of all trips, while home to school trips comprised 9.8 per cent, and other trips 18.7 per cent (Katahira and Engineers International, 2006).

According to King'ori (2007), the main trip flows were concentrated into the centre of the city from the west and east areas of Nairobi. He also noted that 93 per cent of trips had their origins and destinations in Nairobi, while 7 per cent were through traffic. Other studies have found the figure for through traffic to be 0.2 percent (CES and APEC, 2010).

In terms of the modal share of trips, different studies have shown different results for the various modes of transport as shown in Table 2.2. This can be attributed to the different methodology, traffic analysis zones and geographical scope used. However, from the results, it can be seen that majority of trips are executed by non-motorized transport (NMT), that is, walking and cycling (49%) followed by public transport and least of all, private car.

The studies shown in Table 2.1 also reveal that 54 per cent of people living in households which did not own a car, walked to their destinations while 34 per cent were dependent on public transport. In the households which had a car, 52 per cent utilized it for their travel (Katahira and Engineers International, 2006). A study by Salon and Gulyani (2010) revealed that the majority of slum residents (poor residents) in Nairobi could not afford any of the motorized transport options; they thus resorted to limiting their travel and 'choosing' to walk.

Vehicle occupancy rates in Nairobi for the years 2005, 2006 and 2010 are presented in Table 2.3. The rates for the private car have not changed between the years. The most significant variation is recorded for buses, with a difference of 14 occupants between 2005 and 2010.

**Table 2.2: Modal split in Nairobi (%)**

Mode share (based on different studies and years)				
Mode	Nairobi Metropolitan Growth Strategy Report 1973	Aligula <i>et al.</i> , 2005	Katahira and Engineers International, 2006	CES and APEC 2010
Walking and cycling (Non-motorized transport)	47.2	49	49	-
Private car	39	9	15	31
Public transport	13.7	42	36	69
Other		-		

NB: The studies differ in terms of design and geographical extent of Nairobi covered and this could account for some of the variation.

Source: Aligula *et al.* (2005); Katahira and Engineers (2006); and CES and APEC (2010)

**Table 2.3: Vehicle occupancy rates in Nairobi**

Vehicle type	Vehicle occupancy (based on different studies and years)		
	Aligula <i>et al.</i> , 2005	Katahira and Engineers International, 2006	CES and APEC, 2010
Private car	-	2	2
Matatus	12	14	11
Bus	40	34	26

Source: Aligula *et al.* (2005); Katahira and Engineers (2006); CES and APEC (2010)

## **2.9 Transport Policy, Legal and Institutional Framework**

### **2.9.1 Transport policy**

The Integrated National Transport Policy 2009 provides the framework that governs the transport sector in Kenya under the theme “moving a working Nation.” It is tailored towards the achievement of Kenya Vision 2030 in which the transport sector is identified as a key enabler. The vision of the policy is “A world-class integrated transport system that is responsive to the needs of people and industry.” The mission statement reads “To develop, operate and maintain an efficient, cost effective, reliable, safe, secure and integrated transport system and link transport policy with other sectors in order to achieve national and regional development aspirations in a socially, economically and environmentally sustainable manner”.

### **2.9.2 Legal regulatory and institutional framework of the transport sector**

According to the Integrated National Transport Policy 2009, the transport sector is governed by a number of statutes that fall under two broad categories, namely those affecting all sectors of the economy, and those that are sector-specific. It mentions that many of the sector-specific laws are outdated and require urgent review to enhance effectiveness. A summary of the statutes and regulations are provided in Appendix I. Some of the main institutions concerned with the transport sector include: Ministry of Transport, Ministry of Roads (MoR), Kenya National Highways Authority (KeNHA), Kenya Rural Roads Authority (KeRRA), Kenya Urban Roads Authority (KURA), Transport Licensing Board (TLB), Kenya Police (Traffic Department), local authorities and county governments, amongst other non-state actors (CES and APEC, 2010).

### **2.10 Traffic Congestion in Nairobi**

The Nairobi urban transport system has been shaped by population pressure, urban structure and the prevailing general transport system (Aligula *et al.*, 2005). This has led to numerous transport problems that can be attributed to the high population growth rate, increased vehicle ownership, lack of proper traffic control and management, lack of proper planning for transportation, low vehicle capacities, high energy costs,

poor provision and utilization of infrastructural facilities, inefficient spatial distribution of land uses, lack of road and vehicle infrastructure development and maintenance, lack of discipline among road users, poor road safety, among others. These factors lead to problems such as traffic congestion, road accidents, environmental pollution, inefficient modal split, constrained growth and economic activity, social problems such as inequality and health complications, among others (Aligula *et al.*, 2005; and King'ori, 2007).

Various studies have established that there is indeed traffic congestion in the Nairobi urban road transport system. Gonzales *et al.* (2009) analyzed the street network of Nairobi and its ability to serve motorized vehicle trips, including private cars and informal paratransit vehicles (*matatus*). They observed that traffic congestion was a growing problem in Nairobi, resulting from rapidly increasing population and crowding of motorized traffic onto a limited street network and that as demand grows in the future, the streets will quickly become more congested. Their study noted that traffic conditions in Nairobi were characterized by concentration of vehicles on a limited network and lack of redundancy (a condition in which there are no more than one or two reasonable routes for any origin-destination pair) and this was evident from the fact that in order to enter into the city centre, vehicles were limited to passing through one of six gateway traffic circles on the CBD edge. They also noted that travel on Nairobi's street network is unreliable because congestion can arise unexpectedly and last for hours, with the possibility that small localized incidents may have widespread effects. Their study recommended that the rate at which vehicles can enter the CBD should be metered in to control accumulation; that policies to reduce peak travel demand by shifting trips to public transport or spreading the demand across more time in the evening should be adopted; that capacity in the network should be increased by converting roundabouts into signalized intersections and adding redundancy to the network; and strategic investment in the transport network was needed to improve its performance .

According to King'ori (2007), traffic congestion was prevalent on the radial trunk roads in Nairobi, in particular on Thika Road, Uhuru Highway and Mombasa Road. The author observed that there was also heavy traffic congestion during peak hours. It was recommended that congestion should be viewed under three elements, namely the demand side (socio-economic activity, individuals, households, companies

and commodities); the supply side (transportation system); and the institutional and regulatory framework.

In order to provide information of road sections that were subject to undue traffic congestion, CES and APEC (2010) conducted speed and delay surveys in Nairobi using the moving car observer method. It was found that on nearly 57 per cent of the surveyed roads, the attainable speed was less than 30kph. It was also observed that delays constituted 7 per cent of total journey time. Mono nuclei pattern of Nairobi concentrates employment within the CBD and is a primary cause for a host of transport problems, including traffic congestion. Also, it mentioned that the transport system is composed of radial roads and railway lines all converging onto the CBD, and that there are missing circumferential links; a situation that further exacerbates the congestion problem (Ibid).

Lack of access control was identified as one of the major causes of traffic congestion in Nairobi (Post Buckley International Inc. 1998 cited in Howe and Bryceson, 2000). Their report notes that traffic congestion was also caused by encroachment of the road carriageway by NMT, blocking of the carriageway by public transport vehicles as they picked or dropped passengers, as well as on-street parking that blocked smooth flow of traffic. The authors also mention that the main road system in Nairobi “was reasonably well planned and spacious” but that its development has not been at par with the rapid population and road traffic growth, thus leading to congestion. This situation is further exacerbated by lack of circular routes to bypass the CBD (also mentioned in Gonzales *et al.*, 2009), and lack of proper traffic management measures. The unfavourable travel conditions in Nairobi were further highlighted, with a mention that the journey to work for most employed people in Nairobi occupies 2 to 4 hours per day, which placed it “in the same category of inconvenience as Mexico City, Sao Paulo, and Shanghai”, which had much bigger population numbers and higher levels of vehicle ownership (Ibid).

According to Howe and Bryceson (2000), the parking problem in the CBD was brought about by lack of control over land use, which was manifested by the rapid speculative construction of high-rise office buildings with no addition to on-street parking capacity as provided for in the building code (by-laws). They also observed that there was congestion of human traffic during rush hours due to restricted road space.



The appraisal report for the Nairobi-Thika superhighway improvement project prepared by Oumarou and Kulemeka (2007) identifies that alleviation of traffic congestion is one of the main objectives of the project. The report mentions that the rapid urbanization trend coupled with explosive growth in motorization and a disorganized public transport system has resulted in chronic traffic congestion in Nairobi. The situation is made worse by heavy flows during peak hours, as well as competition and conflict for limited road space by road users. The report outlines the seriousness with which the Government of Kenya and development partners such as the African Development Bank (AfDB) attach to the problem of traffic congestion.

### **2.11 Traffic Congestion Mitigation in Nairobi**

Various efforts have been put in place to address the problem of traffic congestion in Nairobi. Aligula *et al.* (2005) recommended that the transport supply system should be reorganized to take into account growth patterns by shifting towards a high capacity/occupancy system away from a single-person system. They also recommend a focus on infrastructure supply optimization policies that enhance utilization of existing facilities maximally, development of missing links within the transport system to move traffic away from the CBD, development of a network of non-motorized transport lanes, integrated urban land use and transport planning policies that vest the powers to plan for and control land use in an independent body, a shift towards environmentally friendly fuels, application of economic instruments such as parking fees, promotion of public transport, pedestrianization of the CBD, and finally the need to focus on the acquisition, management and dissemination of detailed information required for urban transportation planning and management. The NUTRANS report highlighted the urgent need to increase the urban transport supply through construction of missing links, improvement of major urban corridors, and a gradual shift to mass transit systems such as Bus Rapid Transit (BRT) and Light Rail Transit (LRT).

The report by CES and APEC 2010 looked at the feasibility of Mass Rapid Transit Systems (MRTS), namely: Bus Rapid Transit (BRT) and Light Rail Transit (LRT) systems in Nairobi. The MRTS would lead to a significant reduction in traffic volume on the study corridors. The study also proposed a Nairobi Metropolitan Multimodal Transport Plan composed of multimodal transport, travel demand management

measures, transit-oriented development, redevelopment and traffic management of the CBD, among other measures to address transport problems in the city. Recommendations on policy, legal and institutional restructuring of the transport and allied sectors were also provided.

There are currently eight (8) public agencies addressing transport and congestion issues within Nairobi. These are MoT, MoR, MoNMD, MoLG, KURA, KeNHA, Traffic Department of Kenya Police, and CCN. The private sector has also addressed the problem of traffic congestion with examples of Access Kenya providing web-based real time surveillance of traffic conditions via traffic cameras, and radio stations providing regular traffic updates especially during peak hours. These initiatives help commuters to plan their journeys before hand and avoid congested routes.

Appendix II provides a summary of the different congestion mitigation measures proposed and/or implemented in Nairobi. These are benchmarked against best practices that Litman (2003) refers to as win-win transportation solutions.

### **3. Literature Review: Road Traffic Congestion**

“Traffic congestion is people with the economic means to act on their social and economic interests-getting in the way of other people with the means to act on theirs” (Favourite saying by: Alan E. Pisarski, 2006).

#### **3.1 Understanding Traffic Congestion**

Lindsey and Verhoef (2000) note that traffic congestion is one of the major liabilities of modern life, and that it is a price that people pay for the various benefits derived from agglomeration of population and economic activity. Weisbrod, Vary and Treyz (2003) define traffic congestion as a condition of traffic delay when traffic flow is slowed below reasonable speeds because the numbers of vehicles using a road exceed the design capacity of the transport network. This can be interpreted to mean that congestion is a situation in which demand for road space exceeds supply (Rodrigue *et al.*, 2009). A report prepared in 2007 by the Organization for Economic Development (OECD) and European Conference of Ministers of Transport (ECMT) defines traffic congestion as “a physical phenomenon relating to the manner in which vehicles impede each others’ progression as demand for limited road space approaches full capacity”. The report further notes that road traffic congestion is also a “relative phenomenon relating to user expectations vis-à-vis road system performance” (OECD/ECMT, 2007). Rodrigue *et al.* (2009) add that “congestion can be perceived as an unavoidable consequence of the usage of scarce transport resources, particularly if they are not priced.”

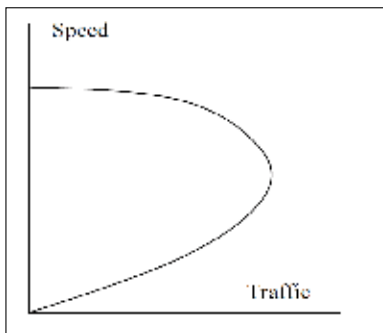
Goodwin (2004) defines congestion as the impedance vehicles impose on each other due to the speed-flow relationship in conditions where the use of a transport system approaches capacity. The speed flow relationship is based on the fundamental scientific relationship in traffic engineering, which holds that the more traffic tries to use a road or a road network, the slower it goes. The speed flow relationship is illustrated by the speed flow curve shown in Figure 3.1. At very low levels of traffic volume (free flow), changes in the number of vehicles have little effect. But as traffic volume increases, even very small increases or reductions in traffic will have a disproportionately large effect on speed. Litman and Doherty (2011) add that this is because congestion is a non-linear function. Goodwin (2004) also points out that

the conventional speed flow curve, which is smooth, does not represent the reality appropriately and thus proposes another curve (Figure 3.2) which is more realistic because it shows instability and unreliability in the transport system. This argument is based on the unstable, variable behaviour of traffic in the region, where the road is operating close to its maximum capacity.

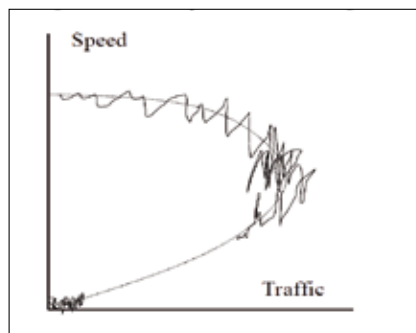
There are various perceptions to road traffic congestion. In some countries, urban traffic congestion is viewed as a critical issue of national importance because it has impacts on productivity, while in countries where travel alternatives exist, it is seen as a self regulating problem. Laetz (1990) observes that reaching an agreement as to what constitutes congestion can be problematic. However, congestion is deemed excessive, thus warranting action, “when the marginal costs to society of congestion exceed the marginal costs of efforts to reduce congestion” (OECD/ECMT, 2007).

Traffic congestion is defined differently by the different professions. According to Thompson (1998), the engineers’ perspective on traffic congestion was that it could be caused by obstruction or inefficient use of the roads, which could be explained by lack of road capacity. This is also referred to as shortage of supply. To establish congestion cost, engineers compare the estimated cost of traffic movement with its theoretical cost under conditions of free flow. Whereas the economists’ concept of congestion is based on the difference in travel costs and consumers’ surplus between actual flow and optimal flow, this differs from the engineers’ concept in the sense that the economists recognize

**Figure 3.1: Conventional speed flow curve**



**Figure 3.2: Realistic speed flow curve showing instability and unreliability**



that there is an optimal flow, an optimal speed, hence an optimal level of congestion. However, traffic engineers in Germany refer to traffic congestion as the condition where the speed of the vehicles driving on a motorway drops below 30 km/h over a time period of at least 60 seconds (Schwarzmann, 2007).

In order to understand traffic congestion, it is important to perceive it in the context of city dynamics and agglomeration benefits. With this in mind, it can be seen that urban road users are prepared to live with congestion because they derive other benefits from living and working in cities. Thus, in vibrant urban areas, it is difficult to eradicate congestion and at the same time road users accept that they cannot have congestion free roads (OECD/ECMT, 2007). This situation is referred to as the traffic congestion dilemma, which is fundamental in understanding and managing traffic in economically vibrant urban areas. The emerging trend in urban traffic congestion is that the period of time that roads are congested during the day has lengthened, a condition referred to as “peak-spreading”, and the geographic extent of congestion within urban areas has continued to expand (OECD/ECMT, 2007).

### **3.2 Causes of Traffic Congestion**

The main cause of road traffic congestion is that the volume of traffic is too close to the maximum capacity of a road, which makes the road extremely vulnerable to sudden breakdowns or interruptions (Goodwin, 2004; OECD/EMCT, 2007). In order to get a better understanding of the causes of traffic congestion, it is important to consider the basic principles of trip generation in relation to how trips are produced and attracted to an area within a given time. The concept that travel is a derived demand comes to mind. It holds that people move from one location to another in order to participate in certain activities that are distributed in space and time, leading to the generation of trips on a given route, using a particular mode of transport at a particular time. It follows, thus, that if there is a large number of trips on the same route at the same time, the different trip makers will impede each other, thus giving rise to trip (traffic) congestion. It is observed that vehicles following each other too closely will generate shock waves, and the car that gets closer to the vehicle in front must slow down more often than the car in front, eventually traffic flow comes to a stand still

(Schwarzmann, 2007). This explanation is rather simplified; in reality the causes of traffic congestion are based on a complex mix of factors.

According to OECD/EMCT (2007), there are two categories of factors that cause traffic congestion: micro-level factors and macro-level factors. Micro-level factors are the triggers of traffic congestion related to traffic on the road. Examples of micro level factors fall under the realm of traffic engineering and include road and intersection design. Other factors such as road accidents, stalled vehicles, poor road conditions, road user behaviour and lane switching also fall under this category. Macro-level factors are the drivers of traffic congestion and relate to demand for road use. Examples of macro-level factors include the nature of land use spatial distribution, activity patterns in time and space, income levels, car ownership trends and regional economic dynamics. Traffic congestion in urban areas is an outcome of vibrant economic development, and congestion grows as cities grow and as economic activity expands. Hokao and Mohamed (1999) provide supporting evidence based on their work in Bangkok, where their study found that the ineffective implementation of measures related to land in the city centre was one of the major causes of traffic congestion. Two types of traffic congestion can be distinguished when looking at the causes; the first is recurrent congestion, which occurs due to regular road use such as daily commuting trips on a road operating at or near maximum capacity. The second is non-recurrent congestion, which is the effect of unexpected, unplanned or large events such as road works and crashes (OECD/EMCT, 2007). Schwarzmann (2007) mentions that “about 50 per cent of all traffic congestion on German motorways is caused by road construction or other incidents such as accidents or broken-down cars, while the other 50 per cent is caused by traffic overload.”

De Palma *et al.* (2001) add that congestion is caused by peak loads in travel demand, rigidity of transportation infrastructure, the short-run supply of vehicles and the inability to store transport services. They note that it is made worse by the fact that growth in population and travel is ahead of transportation investment.

Rodrigue *et al.* (2009) observe that under-pricing of infrastructure and consumer choices may lead to traffic congestion. They mention that road infrastructure is subsidized as a public service, and thus suffers the tragedy of the commons, a condition where drivers do not bear the full cost of using vehicles and thus tend to over use the road causing

congestion. They also add that consumers choose the automobile as a symbol of status, freedom and prestige, leading to increased volumes of traffic and ultimately congestion.

The behaviour of road users also has a role to play in the creation of traffic congestion. Increased traffic volumes have an impact on people's behaviour and, following from this, their individual reaction times as well as other parameters affect the number of traffic incidents, leading to traffic congestion. Similarly, the drivers' braking and acceleration habits also affect the smooth flow of traffic (Schwarzmann, 2007).

Culture, norms and values of people may have an impact on traffic congestion. Lugalla (1990) cited in Howe and Bryceson (2000), with reference to a study on Tanzania, mentions that there is a cultural reason for the extraordinary level of traffic congestion despite the low level of motorization and gives the reason as "these are cities of personalized dealings where each appointment has to be done physically and in person and that telephone facilities are inadequate." The author further adds that payments and other transactions such as bills for telephone, water and electricity have to be made in person and, therefore, involve a trip.

### **3.3 Effects of Traffic Congestion**

Traffic congestion can be analyzed according to its economic, social and environmental effects. It should also be noted that within these categories of effects, some might be direct, while others are indirect.

Hartgen and Fields (2009) undertook research on the effect of traffic congestion on regional economic performance by studying how accessibility affects the performance of eight (8) urban regions in the United States of America (USA). The number of jobs/residents within a given drive time from different points (accessibility) was correlated with regional productivity in terms of gross regional product per worker. They quantified how much current and future traffic congestion and total congestion relief would affect the economic productivity of each region. The study found that the Central Business District (CBD) was generally the most accessible place in each region, with up to 60 per cent of jobs and 50 per cent of residents. It was determined that rising traffic congestion and rapid suburban growth would reduce the accessibility of key points in most regions by 1-10 per cent, but removal of congestion would increase access to key points by 2-30 per cent.

The study also found that a 10 per cent decrease in CBD accessibility would decrease regional productivity by about 1 per cent, and reducing congestion would boost Gross Regional Product (GRP) by 6-30 per cent if targeted at suburbs, malls, and universities; 4-10 per cent if targeted at CBDs, and just 2-8 per cent if targeted at airports. Increased regional productivity and tax revenues were identified as some of the benefits to be accrued from free-flowing traffic conditions. The study concluded that as regions grow and other locations become relatively more congested, the focus of transportation plans on CBD access would be misplaced, and it would be more rational to improve access through congestion reduction, particularly in non-CBD locations.

Weisbrod, Vary and Treyz (2003) examined how urban traffic congestion imposes economic costs within metropolitan areas. They investigated how various producers of economic goods and services in Chicago and Philadelphia were sensitive to congestion, through its impacts on business costs, productivity and output levels. They found that sensitivity to traffic congestion varied by industry sector because of the differences in each sectors' mix of required inputs. It was observed that each sector differed in its reliance on access to skilled labour, access to specialized inputs and access to a large transportation based market area. Their study also demonstrated how congestion effectively shrunk business market areas, reduced worker access to jobs and shopper access to stores, reduced "agglomeration economies" and increased production costs of businesses in urban areas, thus reducing productivity. In relation to the economic cost of congestion and the economic benefit of congestion reduction, they found that these differed depending on the area's specific economic profile, as well as its unique pattern of congestion. The findings by Weisbrod, Vary and Treyz (2003) bear some resemblance with the work by Ulengin (1994) who found that easing of traffic congestion is expected to result in an increase in jobs and business opportunities as well as intra-regional and inter-regional trade. Rogat (2010) also adds that the efficiency of a city is determined by the ease at which people and goods can move through it.

Various scholars have adopted the concept of 'value of time' while addressing the economic costs of traffic congestion. Goodwin (2004) mentions that the method used when computing the cost of congestion is based on calculating an average traffic speed, comparing that with what the speed ought to be, and multiplying the short fall by the value of time. A study by International Business Machines - IBM (2009), found



that the value of time consumed commuting was enormous, with 75 per cent of respondents in the study indicating that every 15 minutes stuck in traffic was worth US\$ 10-20; that is approximately US\$ 40/hour. According to Schrank and Lomax (2009), congestion costs in the USA were increasing, and it was noted that the cost of extra time and fuel in 439 urban areas was US\$ 16.7 billion in 1982 and US\$ 87.2 billion in 2007.

Traffic congestion is characterized by slower speeds and increased travel times, which impose costs on the economy and generate multiple impacts on urban regions and their inhabitants, for example, in the form of personal and productive time lost and fuel wasted (OECD/EMCT, 2007; Weisbrod *et al.*, 2003). Rodrigue *et al.* (2009) mention that it is common for transport costs to account for 10 per cent of the total cost of a product. An example from Beijing based on an analysis of different externalities of car transportation shows that social costs induced by motorized transportation are equivalent to about 7-15 per cent of Beijing's GDP (Creutzig and He, 2009).

Litman (2003) observes that there are several external costs associated with automobile travel; these are, parking subsidies, crash damages, traffic congestion, environmental costs, road way/traffic services and fuel externalities. Traffic congestion is among the top three costs.

Besides the economic effects, traffic congestion has a number of adverse social impacts that affect the quality of life, well being and life expectancy of urban residents. Many non-road users are also exposed to the negative impacts of congestion. The impacts range from adverse effects on quality of life, stress, safety and health and they are experienced in different ways by different people depending on their socio-economic status, location in the city, modes of transport used and the adaptive strategies they undertake (Kritikou *et al.*, 2008; Punpuing, 2001).

Commuting takes a toll on people's health and work performance, and is seen as one of the most stressful experiences of urban life. Increased blood pressure, lowered job satisfaction, higher illness rates, absenteeism and lower performance on various cognitive tasks are related to longer or more difficult commutes (Center for Urban Horticulture cited in IBM, 2009). According to the IBM (2009) study, 44 per cent of all drivers surveyed reported that traffic congestion increased their stress levels. Twenty five (25) per cent of respondents

reported feelings of increased anger and 16 per cent reported that traffic challenges negatively affected work or school performance, while 11 per cent reported getting less sleep due to travel time. When asked how they would spend their extra time if their commutes could be reduced, 52 per cent reported that they would spend it with family/friends, 37 per cent would partake in recreation, 37 per cent would exercise, 33 per cent would sleep more and 11 per cent would work more.

Zhang and Batterman (2009) investigated the changes in time allocations and exposures that result from traffic congestion and found that children and retirees primarily reduced the time spent at home because of congestion, while for working adults, congestion shifted the time spent at home, school, public buildings and other indoor environments.

Traffic congestion also leads to an increase in traffic accidents, which results in death and serious injuries that adversely alter the lives of the victims (Schwarzmann, 2007). Ulengin (1994) observed that the social benefits of solving the transportation problem between the European and Anatolian sides of Istanbul were improved safety and reliability, improved communications and saved time.

By conceptualizing traffic congestion as an environmental stressor that impedes one's movement between two (2) or more points, Stokols *et al.* (2007) conducted a study to assess the effects of routine exposure to traffic congestion on the mood, physiology, and task performance of automobile commuters. The study found that traffic congestion caused annoyance and was correlated to systolic and diastolic blood pressure, and that the commuters who had a greater distance and duration of commute exhibited lower levels of frustration tolerance.

Currie and Walker (2011) studied the effect of reduced traffic congestion and emissions from motor vehicles in the vicinity of highway toll plazas through the introduction of an electronic toll collection system. They compared infants born to mothers living near toll plazas and thus experienced reduced traffic congestion, to infants born to mothers living near busy road ways but away from toll plazas and thus experienced traffic congestion. They found that reductions in traffic congestion reduced the incidence of pre-maturity and low birth weight among mothers within 2km of a toll plaza by 10 per cent and 11 per cent, respectively. The study demonstrated that traffic congestion was a significant contributor to poor health in affected infants.

Rogat (2010) relates travel time to welfare and performance at work for employees, noting that the ideal travel time to get to work should be 30 minutes, and that any travel time greater than 1 hour per day would lead to considerable reduction in the quality of life.

Road traffic congestion brings about detrimental impacts to the biological and physical environment. One of the most significant adverse environmental impacts caused by traffic congestion is air pollution. Vehicles are powered by the combustion of petrol and this combustion produces various air pollutants, including Carbon monoxide (CO), Carbon dioxide (CO<sub>2</sub>), Nitrogen oxides (NO<sub>x</sub>), Volatile Organic Compounds (VOC), and Particulate Matter (PM<sub>10</sub>). The severity of air pollution due to combustion of petrol is further determined by the type of petrol and additives/catalysts used, such as lead and benzene, among others (Pedersen, 2003). Thus, traffic congestion has adverse impacts on air quality due to additional vehicle emissions, which increase air pollutant exposure of urban populations brought on by increased time spent in traffic (Zhang and Batterman, 2009; Weisbrod, Vary and Treyz, 2003). Bangkok, Srisurapanon and Wanichapun (2001) observed that according to the Pollution Control Department (PCD), the air pollutants of greatest concern were PM<sub>10</sub> and CO, which were accounted for mostly by the transport sector.

The emissions from combustion of petrol have severe impacts on the environment and climate change, since most of the air pollutants are categorized as green house gases (Creutzig and He, 2009). Transport accounts for 26 per cent of global CO<sub>2</sub> emissions, while in the United States it accounts for approximately a third of the CO<sub>2</sub> inventory (Chapman, 2007; Barth and Boriboonsomsin, 2009).

Traffic congestion also leads to unsustainable trends in natural resource utilization. Srisurapanon and Wanichapun (2001) note that majority of energy in Thailand is predominantly consumed in the transport sector, and traffic congestion increases the rate of this consumption. Other resources that are consumed on account of traffic congestion include land and land-based materials, which are taken up for the construction of new roads to increase road capacity as a strategy of dealing with congestion (OECD/ECMT, 2007; Thompson, 1998).

Luo *et al.* (2007) mention that the main reason for congestion pricing is the external cost of congestion. According to the authors, the production mechanism of urban traffic congestion is based on the fact that travellers overlook the negative externality of urban traffic

congestion, and then join the already congested queues. They observe that the external costs of urban traffic congestion can be divided into four parts, namely: extra travel time costs, environmental pollution costs, traffic accident costs, and fuel consumption costs.

### **3.4 Traffic Congestion Mitigation**

When addressing the challenges of traffic congestion, it is important to understand that urban regions will never be free of congestion and that fully eradicating roadway congestion is neither an affordable, nor feasible goal in economically dynamic urban areas. What this means is that the focus of any policy or strategy should be on seeking ways to manage congestion in order to mitigate its adverse impact on urban travellers and regions (OECD/ECMT, 2007). Various policies and strategies have been advanced to address traffic congestion.

The strategies are categorized into those based on the road/supply side measures (i.e. transport infrastructure, traffic operations and traffic management); and those based on off the road/demand side measures (i.e. travel demand/mobility management and land use planning) (OECD/ECMT, 2007; Goodwin, 2004; Weisbrod *et al.*, 2003; and Litman, 2003).

According to OECD/ECMT (2007), there are three strategic traffic congestion mitigation principles that should guide policies. First, policies should ensure that land use planning and the community objectives it embodies is coordinated, with congestion management policies; second, policies should deliver predictable travel times; and third, policies should manage highly trafficked roadways to preserve adequate system performance.

One of the most common strategies adopted to manage traffic congestion is the design and construction of new roads or modification and expansion of existing ones in order to increase capacity. This is obviously logical because, as we have seen from its definition, congestion is a condition where traffic volume exceeds the road capacity. Increasing road capacity helps reduce traffic congestion. However, the new road capacity is likely to be rapidly exceeded by previously suppressed and new demand, thus eroding any expected gains (Goodwin, 2004; OECD/ECMT, 2007; Thompson, 1998). Based on the concept of induced travel demand (Figure 3.3), it has been found that “building and expanding roads leads to increased rather than decreased congestion and

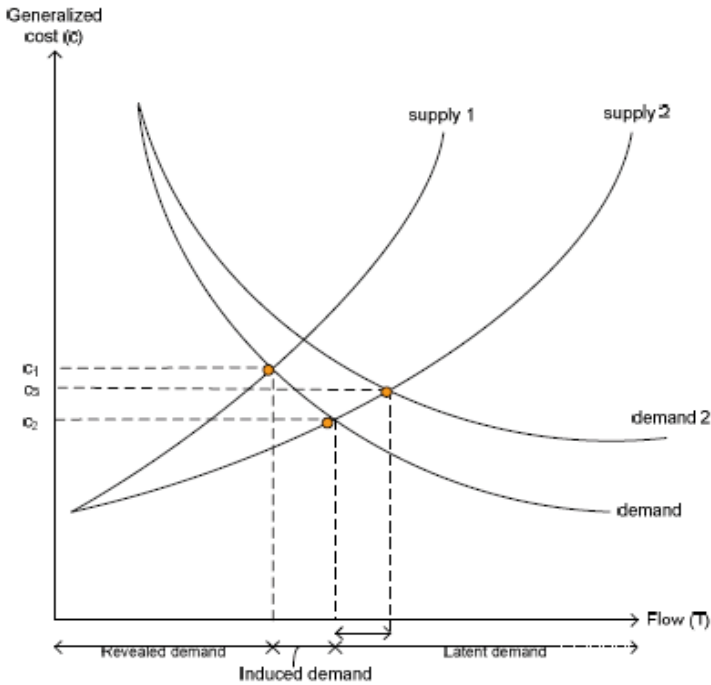
ultimately induces higher levels of travel demand” (Santos *et al.*, 2010). This is because the extra capacity reduces the general cost of travelling, making it less expensive (*ibid*).

Goodwin (2004) adds that “the higher the level of congestion, the greater the amount ‘latent’ traffic is likely to be and therefore the shorter the period of relief from congestion provided by a voluntary shift in choice from some sections of the market.” Lindsey and Verhoef (2000) further add that because land is scarce and road capacity is expensive to construct, it is uneconomical to invest in so much capacity that travel were congestion free. They also note that demand for travel depends on the cost, hence improvements in travel conditions induce people to take more trips due to reduced cost of travel, making it impossible to eliminate congestion. Yawson and Pappoe (2010) observe that road expansion projects designed to alleviate traffic congestion in Accra, Ghana had not been successful. They noted that even with implementation of the projects, congestion got worse and road users indicated that their travel time had increased.

According to Rodrigue *et al.* (2009), the cycle begins with public pressure for an increase in capacity of congested links. When the new capacity is provided, movements become easier, leading to urban sprawl and increased length of movements. The number of movements also increases and the outcome is congestion on the new capacity provided.

Provision of alternative routes by for example construction of new road links and by-pass roads also helps to reduce traffic congestion because the additional routes increase the redundancy of the transport system and distribute traffic that would otherwise be congested on fewer routes (Gonzales *et al.*, 2009). However, it is observed that road users will switch their normal daily routes to avoid congestion, and by so doing congestion will be shifted to the new roads that were previously un-congested (Vanderbilt, 2008).

Improving traffic operations management is a strategy with much potential to mitigate traffic congestion. Instruments under this strategy include road traffic information systems (intelligent transport systems), pre-trip guidance, coordinated traffic signal systems and dynamic speed and incident management policies. According to OECD/ECMT (2007), traffic operation management strategies are cost-effective and help to improve travel and should be used to manage traffic so that flows are held below the limit of the physical facility.

**Figure 3.3: Revealed, induced and latent demand**

Traffic calming and management measures function to reduce traffic congestion by limiting or managing traffic levels and reducing vehicle miles travelled (VMT) and speeds on roads (Litman, 2003). According to OECD/ECMT (2007), traffic management measures seek to directly manage the physical access to the road through access policies such as ramp metering, zone-based access and one way streets. Traffic management measures are also geared at indirectly managing access to the roadway network and directly influencing road travel to particular areas through parking policies. Finally, traffic management measures seek to manage the level of traffic through road pricing policies (also referred to as congestion pricing), which target the use of or access to roads or urban areas such as cordon charges, link based pricing, pay as you drive pricing, and toll roads. Also related to these are instruments such as fuel taxes-tax shifting and commuter financial incentives (Litman, 2003). The use of high-occupancy-toll lanes has emerged as an alternative solution to road pricing (Li, 2001).

Flexible working schedule (flexitime) is yet another traffic management strategy that can be used to mitigate traffic congestion in urban areas (Litman, 2003). According to Rubin (1979), the concept of

flexitime is based on the assumption that in many work situations, rigid starting and stopping times are unnecessary and could be adapted into a more flexible system. The author notes that under the flexitime system, a business may be open from 7:00am to 6:00pm, with all employees present from 9:00am to 3:00pm, arriving between 7:00am and 9:00 am and departing between 3:00pm and 6:00pm. He also mentions that traffic congestion can be eased by spreading out the time during which people travel to and from work and the community also benefits from reduced rush hours. Zhang *et al.* (2005) add that flexible or staggered work hour schemes are effective in reducing morning and evening peak hour congestion as well as saving total work hours because people can work more efficiently by choosing their preferred work schedule. Their study also found that introducing a flexible work hour scheme had several effects, such as attracting more workers to the CBD and encouraging people to stay at home longer in the morning.

Travel demand management strategies are implemented as off the road measures aimed at addressing traffic congestion, and they seek to integrate land use planning principles, amongst other measures, in order to control the nature and scope of travel demand (Guller, 2005; Geurs and Van Wee, 2004; Santos, 2010; and Litman, 2003). It is noted that land-use and transport are related to each other through strong reciprocal interaction and are both essential to the economic and social well-being of society and the environment. The spatial distribution of land use (activities) creates the demand for travel because people need to make trips to and from the various activities. Therefore, the integration of land use and transport planning is advanced as one of the best strategies in urban travel demand management components (Guller, 2005; Geurs and Van Wee, 2004; Tillema 2004; and Litman, 2003). Examples of travel demand strategies that entail land use planning include smart growth strategies such as higher-density development, clustered activities, infill (brownfield) development, mixed land use, location efficient planning, human scale smaller blocks and roads, multi-modal transportation and land use patterns that support walking, cycling and public transit such as Mass Rapid Transit and Bus Rapid Transit (Litman, 2003).

In conjunction with travel demand strategies, mobility management has been proposed as a sustainable strategy to deal with traffic congestion. Mobility management strategies aim to reduce car use in urban areas and they include such approaches as ride-sharing, car sharing, car pooling, park and ride (at times also kiss and ride), school

and campus trip management, mobility management marketing, high occupancy vehicle (HOV) priority, promoting bicycling and pedestrian travel as well as improving public transport (OECD/ECMT, 2007; and Litman, 2003).

In general, there are a number of policy instruments that can be used to address traffic congestion and other related transport problems. Rodrigue *et al.* (2009) mention a few including public ownership, subsidies, regulatory control, research and development, safety and operating standards and labour regulations. Santos *et al.* (2010) provide some examples of policy instruments for sustainable road transport and categorize them into: a) physical policies such as public transport, land use, and road construction; b) soft policies which they describe as “non-tangible and aimed at bringing about behavioural change by informing actors about the consequences of their transport choices and potentially persuading them to change their behaviour”. For example, car sharing, teleworking, teleshopping, eco-driving and advertising campaigns; and c) knowledge policies that focus on research and development for a sustainable model of mobility for the future. They conclude by emphasizing the need for policy combination and integration due to the benefits of positive side-effects and synergies. However, it is important that the merits and demerits of each of these traffic management measures be taken into consideration as part of the policy formulation process.

### **3.5 Empirical Studies on Traffic Congestion Mitigation**

Parry (2002) compared the efficiency of a single lane toll, a uniform congestion tax across freeway lanes, a gasoline tax, and a transit fare subsidy aimed at reducing congestion. It was found that the uniform congestion tax achieved over 90 per cent of the efficiency gains, while the single lane toll, gasoline tax, and transit subsidy forego at least two-thirds of the efficiency gains. However, it was noted that each policy involves some inefficiency. Parry (2002) based on research conducted in Mexico City found that a per mile toll reduced traffic congestion, the largest transport related externality, more directly than the other externalities of air pollution and road accidents.

Hokao and Mohamed (1999) reviewed the various measures that were being taken to mitigate the traffic impact of developments in Bangkok by dividing the mitigation measures into two categories,



namely: those related to land use, and those related to transportation. It was found that measures related to land use were effective in reducing congestion in the area surrounding development, while traffic-related measures were useful in alleviating site-specific impacts. They observed that both measures must be implemented by different stakeholders working cooperatively. The authors recommended that more explicit policy tools for mitigating the traffic impact of new developments should be developed by the Bangkok Metropolitan Administration (BMA). They added that it was necessary to incorporate all possible mitigation measures into the integrated land-use and transportation planning of the city.

Aftabuzzaman, Currie and Sarvi (2011) made use of factor analysis and regression analysis in exploring the traffic congestion relief impact of transit. Their study found that car-deterrence factor had the strongest influence on transit congestion relief, followed by transit-oriented factor and urban-form factor. All the three dimensions had a positive influence.

While comparing the effect of land use instruments and road pricing instruments in mitigating traffic congestion, Brueckner (2007) evaluated the efficacy of the urban growth boundary (UGB) as a second-best substitute for a first-best toll regime in a congested city. The results of the evaluation showed that the utility gain generated by the UGB was a very small fraction of that achieved under a toll regime. It was suggested that a UGB may not be a useful instrument for dealing with the distortions caused by unpriced traffic congestion. Rich and Nielsen (2007) undertook a socio-economic analysis of four different proposed road pricing schemes for Copenhagen area in order to assess the benefits and costs involved. They found that the socio-economic surplus of the projects depended crucially on the level of traffic congestion. The analysis also showed the magnitude of demand response by introducing road pricing, which has a significant impact on the project surplus and that the degree to which benefits outweighed costs depended considerably on the use of revenue, with the observation that in spite of decreasing road congestion, recycling revenue back to the transport sector would be inefficient and costly. However, Hensher and Puckett (2007) observed that travel demand management strategies cannot be successful without a pricing strategy that promotes efficient use of the system and provides revenues to support complementary infrastructure and services such as public transport.

Creutzig and He (2009) studied the external costs and potential impacts of travel demand management with the overall aim of providing help in defining policy instruments that mitigate the adverse impacts of transportation. They analyzed different externalities of car transportation in Beijing and found that a road charge could address traffic congestion. Upon further investigation on the role of demand elasticity in transportation, they demonstrated that joint demand and supply-side policies provided considerable synergies to mitigate adverse impacts.

Kadesh and Roach (1997) while researching on trip reduction ordinances in the USA, looked at the implementation, impact and future changes to the State Commute Trip Reduction (CTR) law in King County, Washington. They found that due to a collaborative approach, the legislation met its short term goal of gaining full participation from employers and was poised to achieve its long term goals of reducing traffic congestion, air pollution and energy consumption. They concluded that mandatory trip reduction programmes that have collaboration between the private and public sectors achieve a greater impact than voluntary programmes. They further add that trip reduction ordinances are similar in cost-effectiveness to strategies involving alternative fuels.

Calfee and Winston (1998) addressed the public policy issue of resistance by commuters in the USA to use congestion tolls to minimize the social costs from automobile congestion. They used stated preference models to estimate the value that commuters were willing to pay to save travel time. They found that the value of travel time was low and insensitive to travel conditions and how toll revenues were used. They also found that even high income commuters who had adjusted to congestion through their modal, residential, work place and departure time choices did not value travel time savings enough to benefit substantially from tolls.

Salomon and Mokhtarian (1997) undertook research on policies designed to curb congestion and found that these have had little effect. They attribute the ineffectiveness to what they refer to as a “gap” between policy assumptions and the manner in which individual users perceive and respond to policy measures. The “gap”, according to them, can be explained by the fact that the set of alternative responses to congestion is wider and different from the one assumed by policy makers, and that the impact of the responses in terms of costs and benefits as perceived by the users create barriers to adoption. They also note that the dynamics

of the behavioural responses are often overlooked by policy makers, and this causes the policies to have little or no effect on user's behaviour.

Moore *et al.* (2010) evaluated vehicle miles travelled (VMT) reduction as a core policy goal for reducing greenhouse gases (GHGs) and found that the economic and social impacts would be too severe given the modest potential of environmental benefits. They observed that VMT reduction instruments such as increasing urban densities could reduce mobility and access to jobs and narrow the range of housing choice. The authors recommend the use of more direct policies such as carbon tax as opposed to what they refer to as broad brushed-blunt instruments of VMT reduction. In addition, Baker (1996) suggests that decreasing traffic congestion to increase average vehicle speed may not always result in a decrease in the levels of some pollutants.

Beevers and Carslaw (2005) analyzed the impact of the congestion charging scheme (CCS) in London and observed that the scheme managed to reduce traffic congestion in the city. On further detailed analysis, they found that between 2002 and 2003, total NOX emissions reduced by  $-12.0$  per cent  $\pm 12$  per cent ( $2\sigma$ ), which was associated to increases in vehicle speed. Similarly, Johansson and Forsberg (2009) studied the effects of a road pricing system on air quality and health in Stockholm. The system was designed such that vehicles were charged for every passage during weekdays and the amount varied during the day, with charges during rush hours being the highest. It was found that the congestion tax system resulted in 15 per cent reduction in total road use within the charged cordon, which would lead to a drop in emission of NOX and PM<sub>10</sub> by 8.5 per cent and 13 per cent, respectively. Consequently, it was estimated that 27 premature deaths would be avoided every year and that this would correspond to 206 years of life gained over 10 years per 100,000 people.

Chin (1996) undertook research on transport policies in Singapore and observed that a tight control over automobile ownership and use in the country has contributed in improving traffic flows, travel speeds and air quality. It was also noted that demand management measures largely focused on controlling the source of traffic congestion, that is, private automobile ownership and its use within the Central Business District during the day. The author further analyzed the effectiveness of road pricing and the vehicle quota scheme (VQS) and found that both measures were instrumental in mitigating traffic congestion, but they also led to the spreading of traffic externalities to other

roads in the network as well as loss in consumer welfare and rent seeking by automobile traders. Seik (1996) looked at various urban environmental policies in Singapore and delved into its regulatory and economic instruments, including its innovative traffic congestion tax scheme, among others. The author suggests that the main factors that contributed to the country's success in using these instruments were its political leadership and technical expertise, economic prosperity, an efficient administration and a supportive law-abiding populace.

Horowitz (1976) mentions that urban environmental and economic problems such as traffic congestion can be mitigated through implementation of measures to discourage the use of low occupancy automobiles and encourage the use of transit and car pools. The author notes that a combination of these measures has the potential to reduce automobile use in cities by approximately 35 per cent. However, it is observed that the effects of traffic reduction programmes on economic activity cannot be established until more operational experience with the programmes is achieved. Based on a web-survey conducted in Portugal on car pooling and car pooling clubs, Correia and Viegas (2011) note that car pooling has had limited success in reducing the number of private cars used because of psychological barriers associated with riding with strangers and poor schedule flexibility. Their study found that car pooling was attached with lower income strata and that saving money was an important reason for participating in it. It was also found that the car pool club did not help to introduce flexibility, but improved interaction and trust among working colleagues.

Shefer (1994) looked at the multiple problems of traffic congestion, air pollution and road fatalities and observed that strategies to address these problems such as congestion pricing, emission fees, reduction of emissions from high-polluting vehicles and introducing more efficient vehicle and/or fuel technologies were not mutually exclusive. The author suggests that these strategies should be employed jointly within an overall strategy and that it is important to investigate the functional relationships between the conflicting objectives of improving urban air quality and reducing road fatalities and traffic congestion. According to the author, such an approach would help decision makers to identify socially optimal levels of congestion that have the highest net social benefit.

Yang (1998) reviewed traffic congestion and air pollution problems in Xiamen, China and analyzed policies adopted by the municipal

government to improve transportation. It was concluded that future transportation in the municipal area should integrate various sectors in a zone, develop public mass transit and build more parking spaces.

Romilly (1999) simulated the effect of substitution of bus for car travel in urban Britain by specifying a spreadsheet model incorporating two types of car (petrol and diesel engine) and three types of bus. The model considered six types of exhaust emission for each vehicle. The simulation results showed that substitution of bus for car travel generally decreased the overall costs, particularly the costs of congestion, but increased exhaust emission costs if bus load factors were insufficiently high. The author recommended that the most effective policy option was to encourage the reduction of particulate emissions from bus engines.

Kanninen (1996) looked at the congestion relief impacts expected of Intelligent Transportation Systems (ITS) in the USA and argued that instead of improving system efficiency, ITS may exacerbate the existing economic inefficiencies in the surface transportation system. However, De Palma *et al.* (2001) observe that increasing the usage of telecommunications technology may help to alleviate congestion by reducing peak-period travel demand. Similar findings are presented by Zhang *et al.* (2005), who found that bottleneck traffic congestion is reduced substantially as more people choose telework with enhanced telecommuting utility. Zhao *et al.* (2010) introduce a Travel Demand Management Strategy known as the Downtown Space Reservation System (DSRS), which is designed to facilitate the mitigation of traffic in a cordon-based downtown area by requiring people who want to drive into this area to make reservations in advance by sending their requests to the infrastructure manager before their trips occur, indicating their desired entry time, exit time, reservation price and other necessary trip details. Based on their research, which involved optimization modules and intelligent systems founded on neural networks, they showed that under known demand patterns, the system was able to pick the “best” trips and achieve the “best” system performance in terms of people throughput and revenue generation. They add that the “intelligent” system can facilitate decision makers to make real time decisions on whether to accept or reject a reservation request.

In Istanbul, Turkey, traffic information is provided to the public by the Traffic Control Centre (TCC), which makes use of traffic cameras, radar sensors and electronic violation detection systems (EDS) to survey traffic in Istanbul and obtain data from which traffic information

is disseminated to motorists by use of intelligent transportation applications. Real time traffic information is broadcast to radios and television channels by a call centre 7 days 24 hours continuously. It is also presented on the web and on mobile phones to the public.

Daly (2011) adds that the use of social media such as Facebook and Tweeter could be at the heart of future traffic congestion mitigation measures. It has been observed that vehicle manufacturers are implementing car mobile applications that will include many social media applications. It is envisaged that “having a city of traffic updaters will allow each street and freeway to be face book updated or tweeted up by the minute, offering drivers a new route to avoid the current traffic jam. Drivers 30 minutes away will be able to alter their routes and decrease the duration spent in traffic.”

### **3.6 What Is The Solution?**

There are many measures to deal with congestion. However, Rodrigue *et al.* (2009) remind us that these measures address the issue of congestion partially because they alleviate but not solve the problem. They note that congestion remains a failure at reconciling mobility demands and acute supply constraints. Weisbrod *et al.* (2003) add that the severity and pattern of congestion as well as the effectiveness of alternative projects or policies to address it can vary widely from area to area depending on its characteristics, and that “there is no single rule of thumb for the economic cost of worsening congestion or the economic benefit of congestion reduction.” Thus, measures to address the problem of urban traffic congestion need to be tailored to the characteristics of the area where congestion is present. In order to manage traffic congestion, Goodwin (2004) recommends strategic actions to reduce traffic volumes, implementation of measures to reduce the intensity of use of scarce road capacity, and that the impact of such measures should be evaluated by comparing them with the cost of implementation.

Finally, congestion is not a problem in itself because it has an impact on both the speed of travel and the reliability of travel conditions. However, the greatest concern to individuals and businesses is on the unreliability of travel conditions due to congestion. Policies and strategies should seek to target reliability of these conditions (unpredictability of travel times), based on the knowledge that congestion is inevitable in dynamic urban areas (OECD/ECMT, 2007; and Goodwin, 2004).

## 4. Analytical and Methodological Framework

### 4.1. Analytical Framework

Transport planners and policy makers have over the years relied on the traditional four step transport model (FSM) to forecast travel demand (Figure 4.1). This model sequentially comprises four sub-steps: trip generation, trip distribution, modal split/choice, and traffic assignment.

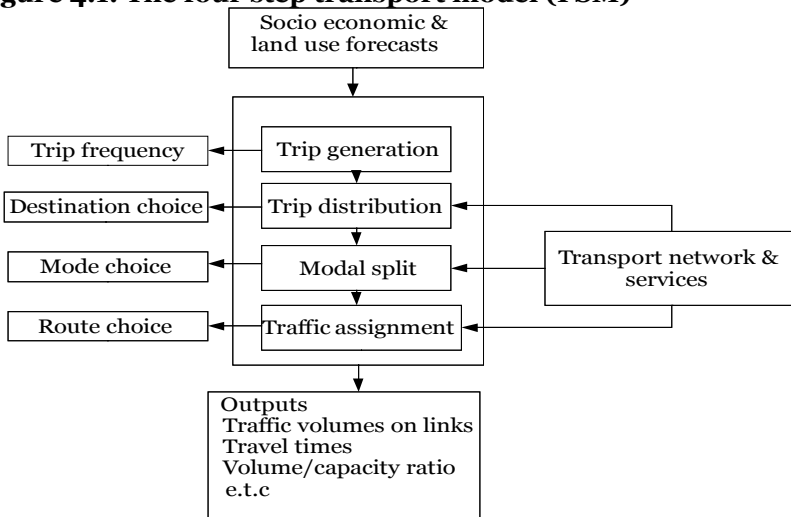
- (a) Trip generation: It makes use of land and socio-economic data such as population, household size and household income, to determine the number of trips produced by and attracted to analysis zones. The socio-economic data is projected into the future based on existing growth rates derived from census data. The quantities of the trips produced and attracted to each zone are taken as symmetrical, meaning that the total trips attracted should equal the total trips produced. The explanation for this is that the basic requirement for travel is produced at one end of the trip, typically the home, and is then attracted to a particular zone that will meet the purpose of the journey (Bates, 2000). This step makes use of regression models or cross classification analysis.

According to Bates (2000) the model of trip production is written as shown in equation 4.1:

$$T_i[k] = f(X^k [C_i^k \dots]) \quad (4.1)$$

where ( $k$ ) is a segmentation of the population (typically a combination of journey purpose and person/household characteristics), ( $i$ ) is the

**Figure 4.1: The four step transport model (FSM)**



origin,  $(X^k)$  is a vector of characteristics for segmentation ( $k$ ) and  $(C_{ij}^k)$  is the composite cost of travelling from the origin.

- (b) Trip distribution: It determines the spatial distribution of trips that are generated in the first step. It makes use of the gravity model to achieve this. The principle is expressed as shown in equation 4.2 (Wells, 1975).

$$T_{ij} = \frac{G_i A_j}{d^n} \quad (4.2)$$

where:

$T_{ij}$  = trips from zone  $i$  to zone  $j$

$G_i$  = total number of trips generated to zone  $i$

$A_j$  = total number of trips attracted to zone  $j$

$d$  = distance or other measure of spatial separation

$n$  = a constant (usually assumed to be between 1 and 2.5)

The relationship is more usually expressed as the equation below (Wells, 1975):

$$T_{ij} = k G_i A_j f(C_{ij}) \quad (4.3)$$

where:

$$T_{ij} \ G_i \ A_j \text{-are as before in equation} \quad (4.2)$$

$f(C_{ij})$  is a function of the separation of the zones ( $i$ ) and ( $j$ ) (a deterrence function/trip decay function which is based on the generalized cost of the journey from ( $i$ ) to ( $j$ )).

$k$ - is a constant.

A matrix of inter zonal trips ( $T_{ij}$ ) can be completed when ( $f$ ) and ( $k$ ) are determined and the trips as well as ( $C_{ij}$ ) are applied (Wells, 1975). The model is commonly referred to as the gravity model with reference to the Newtonian law of gravitational attraction (Bates, 2000).

- (c) Modal split: It shares the trips into different modes of transport such as private car, bus, train and walking. According to Bates (2000), the model of mode choice/split may be written as shown in equation 4.4:

$$\text{Where:} \quad P_m [ij : k] = f(C_{ijm}^k, C_{ij\{m\}}^k) \quad (4.4)$$



$k$  a segmentation of the population

$i$  and  $j$  the origin and destination of the journey

$m$  the mode

$P_m[ij:k]$  the proportion of all travellers of type ( $k$ ) moving between ( $i$ ) and ( $j$ ) who use mode  $m$ , and

$C_{ijm}^k$  the associated cost and  $\{m\}$  is the set of modes being considered.

- (d) Traffic assignment: It allocates the trips in different modes to the transportation network (Levinson and Kumar, 1994; and Tillema, 2004). There are different methods for assignment, namely: the all or nothing assignment, capacity restraint assignment and multi-route assignment. The latter two techniques take account of the unlikelihood of all trips using the single least cost route, while the multi-route method assumes that the driver does not know which is the least cost route and depends on random selection of links (Wells, 1975). The capacity restraint technique depends on the relationship between the volume of traffic and the speed at which traffic can move on a link.

According to Bates (2000), assignment has a number of separate processes, namely, choice of route (or path) for each ( $i$ - $j$ ) combination; aggregating ( $i$ - $j$ ) flows on the links of the chosen paths; dealing with supply-side effects (capacity restraint) as a result of the volume of link flows relative to capacity; and obtaining the resulting cost for each ( $i$ - $j$ ) combination. He further adds that the produced travel matrices are on annual average day basis and assignment tries to relate flows on links to sensible definitions of “capacity”.

The FSM can be viewed in two stages, the first stage relates to characteristics of the traveller and the land use–activity system in which travel demand is measured. The second stage loads this demand onto the transportation network (McNally, 2000). Figure 4.1 illustrates the FSM.

## 4.2 Conceptual Framework

Transport planners seek to model travel demand and predict the effect of transportation system changes in terms of traffic or ridership for a particular link, route or entire transportation network. Transport

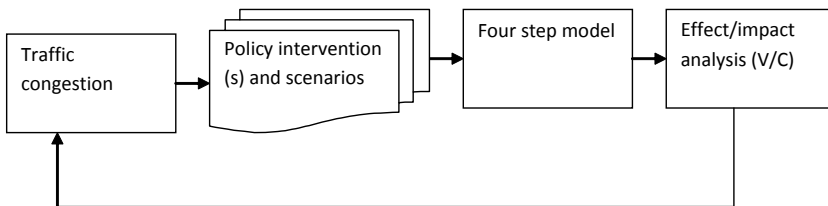
models are used to help in planning transport infrastructure and in anticipating exogenous changes in travel demand patterns (Fox, Daly and Gunn, 2003). The transport model once calibrated and validated, can be used to simulate the effect of the alternative traffic congestion mitigation measures.

Travel demand forecasting models provide forecasts of future travel patterns based on projections of future demographic and socio-economic patterns derived from land use analysis methods and models. Hensher and Button (2000) note that academicians focus on developing transport models that explore the technical efficiency of a transport system, while policy makers are much more interested, for instance, in the impacts of various transport actions.

One of the indicators that transport policy analysts are interested in monitoring is the volume-to-capacity V/C ratio of the transport system; that is, the amount of traffic/passenger car units on a road against the designed capacity of the road. The V/C ratio forms the basis for the level of service (LOS) ratings when evaluating congestion intensity at a particular location. A V/C less than 0.85 is considered under-capacity, 0.85 to 0.95 is considered near capacity, 0.95 to 1.0 is considered at capacity, and over 1.0 is considered over-capacity (Litman and Doherty, 2011). Transport policy makers use this indicator as a measure of transport system performance to help in the design of transport policies and plans (Hensher and Button, 2000; Ortúzar and Willumsen, 2001 and Wells, 1975).

The conceptual framework of this study is summarized in Figure 4.2. From the illustration, traffic congestion will be addressed by policy interventions that will be modelled in the FSM, and their effect on traffic congestion will be quantified using the V/C ratio.

**Figure 4.2: Conceptual framework**



## **4.3 Methodological Framework**

### **4.3.1 Data needs and acquisition**

In order to operationalize the conceptual framework and address the objectives of this research, various data needed to be collected. The data required for this study was identified after extensive literature review and consultation. Due consideration was observed for feasibility given the time and technical constraints.

Land use and socio-economic data needs included the traffic analysis zones (TAZs) for the NMR. These provided one of the main inputs for the model. Some of the attributes of interest were population (age 5 years and above), number of students, number of workers, income, and car ownership, among others.

The transport system data sought included the multi-modal transport network comprising road and rail. Differentiation between private and public transport was required. The networks would have the pre-requisite attributes needed to run the FSM, including the travel speed and capacity. Data on the available traffic mitigation measures in Nairobi was also acquired.

The model calibration and validation data required included the parameters, coefficients, formulae and assumptions to run the FSM model. Due to time constraints, this data was sourced from calibration reports of existing transport modelling studies conducted in Nairobi (NUTRANS) as opposed to the standard practice of primary data collection through household travel surveys. However, this research applied coefficients from the reviewed models to build a travel demand model, which was used to analyze the effects of traffic congestion mitigation measures in NMR. This was identified as a key element of value addition in this research.

### **4.3.2 Data processing, validation and reasonableness check**

The data was assembled and put into a geo-database using ArcGIS DESKTOP 9.3 software application. The pre-analysis processing required the change of format of some of the data into shape file and Flowmap 7.3 software data format in preparation for the analysis.

### *Traffic analysis zones*

The TAZs dataset composed of spatial and attribute data was prepared using ArcGIS. The spatial coverage of the TAZs was based on the administrative units of locations in NMR, which made up a total of 97 TAZs. Attribute data for population above the age of 5 years and for students at school base was derived from the 2009 population census, while attribute data for the workers at office base was derived from the NUTRANS report. All attribute data was collected at the administrative unit level of sub-locations and was later aggregated to location level for analysis. Forecasts were made to the year 2030, for the three attributes of interest. Compounded annual growth rates (CAGR) of 3.9 per cent for Nairobi city and 3.6 per cent for the other metropolitan areas of Thika, Machakos, Kajiado and Kiambu were used to forecast the population to the year 2030. These figures were derived from estimates based on the national census statistics for 1999 and 2009. Forecasts for students were derived from the estimated population in each sub location. The forecasts for workers were based on the estimates in the NUTRANS report.

The data was validated, checked for reasonableness and updated using different approaches. The key approach used was to cross check the land use and socio-economic data against other sources of data, mainly census records where aggregated totals were compared (Wegmann and Everett, 2008; Zhao *et al.*, 2005). The dataset contained reasonable figures for population, workers and students.

### *Road network*

The road network dataset was also prepared in the ArcGIS. Roads in Nairobi city were derived from a dataset prepared by the Centre for Sustainable Urban Development (CSUD), while roads in the metropolitan region were derived from a dataset prepared by Oakar Services Limited. The main attributes of interest were road length, capacity, travel time, road name and classification. These attributes were prepared and computed in ArcGIS, while the capacity attribute was derived from road design guidelines as captured in the NUTRANS report. Additional information on proposed roads, namely the missing links in Nairobi, was derived from the Kenya Urban Roads Authority (KURA) website.

### **4.3.3 Operationalization**

Three travel demand scenarios were simulated using the FSM, namely; the base year scenario without implemented mitigation measures; the forecast year scenario (2030) without implemented mitigation measures; and the forecast year scenario (2030) with implemented mitigation measures. The mitigation measures addressed in this study included: Road expansion projects and plans, the Nairobi by pass project; the missing links project, and the measures in the traffic decongestion programme initiated by the Ministry of Nairobi Metropolitan Development (MoNMD). Besides these, other supply side and demand side traffic congestion mitigation measures informed by literature were evaluated (see section 4.2).

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## 5. Data Analysis

### 5.1 Research Question 1: Travel Demand Model

#### 5.1.1 Trip generation: Productions and attractions

The trip productions and attractions for each TAZ were divided into four categories based on purpose, namely:

- Home-trips bound for home
- Work-work based trips
- School-trips to school
- Others trips such as leisure and shopping

The NUTRANS report provided the estimated linear regression trip generation model and the parameters. The coefficients were operationalized in this research in order to analyze the effects of traffic congestion mitigation measures in the NMR.

The method used to calculate the trip productions and attractions is:

#### **Productions**

$$\text{Home trip productions} = (\text{population age 5 and above} * 0.1018) + (\text{workers at office base} * 1.0279) + (\text{student at enrolment base} * 1.4670) \quad (5.1)$$

$$\text{Work trip productions} = (\text{population age 5 and above} * 0.05226) \quad (5.2)$$

$$\text{School trip productions} = (\text{population age 5 and above} * 0.2131) \quad (5.3)$$

$$\text{Others trip productions} = (\text{population age 5 and above} * 0.3102) + (\text{Workers at office base} * 0.1888) \quad (5.4)$$

#### **Attractions**

$$\text{Home trip attractions} = (\text{population age 5 and above} * 1.0317) \quad (5.5)$$

$$\text{Work trip attractions} = (\text{workers at office base} * 1.0165) \quad (5.6)$$

$$\text{School trip attractions} = (\text{student at enrolment base} * 0.9476) \quad (5.7)$$

$$\text{Others trip attractions} = (\text{population age 5 and above} * 0.2109) + (\text{workers at office base} * 0.3341) \quad (5.8)$$

The base year 2010 socio-economic attributes were projected to the year 2030, and the trip generation model was applied to the projected TAZs dataset.

### 5.1.2 Trip distribution

This step shows how the generated trips were distributed across Nairobi Metropolitan Region. Trip distribution was carried out using flow map 7.3 software. The shape file of the TAZs with the calculated productions and attractions was converted into flow map format with productions and attractions being the main attributes of focus. The road network was also converted to flow map format.

In this step, the task was to match the origins and destinations to develop an O-D trip table which is a matrix that displays the number of trips going from each origin to each destination. The doubly constrained gravity model was used for trip distribution, where the productions and the attractions were used to fit the distribution function. Flow map allows introduction of different types of decay functions, namely: the exponential, power and the tanner function. The mean trip length (MTL) and beta value were also used to produce a trip proportional fit.

In flow map, a distance table from each zone to every other zone using the network has to be created before execution of the gravity model. The network distance table was created using the following:

- Impedance attribute: Travel time in minutes
- Impedance unit: Minutes
- Conversion factor (to map units): 0.00240

The origins and destinations in Flow Map are depicted as the centroids of zones. The intra-zonal distance, which is the average distance to go from the zone centroid to the network, was calculated on the basis of equation 5.9:

$$C_i = 0.667\sqrt{(S_i / \pi)} \quad (5.9)$$

where  $C_i$  is the intra-zonal distance of the area (i) and  $S_i$  is the surface (SIZE) of zone (i)

In flow map, this was calculated using equation 5.10 using the calculate field option.

$$\text{Intrazonal Distance} = 0.667 \times (\text{SIZE} / \#pi)^{0.5} \quad (5.10)$$

Having developed the network distance table, the next step was to actually perform the doubly constrained gravity model. The origin constraint applied was the production field from the TAZs and the

destination constraint was the attraction field. The distance decay function was set to exponential, with the assumption that the propensity to travel decreases proportionately with distance and the decrease is quick. An MTL of 15 was used to calibrate the beta value of the gravity model. The convergence criterion for all cases was set to 10 per cent.

### 5.1.3 Modal split

The modal split was undertaken using the flows generated from the gravity model output. It was carried out in flow map. The flow-file in data base format (DBF) derived from the trip distribution step was used to share the person trips into different modes. According to the NUTRANS report, the share of private car mode was 15 per cent and that of public transport was 36 per cent for the base year. While in the year 2030 the share of private mode used was 26 per cent, that of public transport was set at 30 per cent. The average occupancy rates and passenger equivalent car units (PCU) factors for the different vehicle types were derived from the MRTS report. These rates were used to convert the person trips to vehicle trips using the following equations:

$$Car\_trips(2010) = \frac{(SCORE \times (15/100))}{2.2} * 1.1 \quad (5.11)$$

$$Public\_transport\ trips(2010) = \frac{(SCORE \times (36/100))}{12.5} * 2.5 \quad (5.12)$$

$$Car\ trips(2030) = \frac{(SCORE \times (26/100))}{2.2} * 1.1 \quad (5.13)$$

$$Public\_transport\ trips(2030) = \frac{(SCORE \times (30/100))}{12.5} * 2.5 \quad (5.14)$$

where *SCORE* is the attribute field for flows of person trips in the flow map DBF flow file

### 5.1.4 Assignment

The assignment step presents the methodology applied for the traffic assignment step of the FSM. It relies on the outputs derived from the modal split step. Upon completing the modal split, the following step was to assign the vehicle trips to the road network. The private car and public transport trips were assigned to the transport network using flow map.



The All or Nothing (AON) assignment method was used, also called the shortest path method. It assigns all traffic flows between origin-destination (O-D) pairs using the shortest path. Assumptions of this modelling technique are:

- That travellers want to use the minimum impedance route between two points
- That all trip makers have precise knowledge of the travel time on the links
- That all drivers will use the fastest route without regard to congestion caused by other vehicles
- That travel time on links do not vary with link flows

In flow map, the flow assignment to network function was used. Private car trips and public transport trips were assigned separately to the network. The impedance attribute used was minutes and the connect method was lines. Flows were assigned on the basis of starting or ending halfway to a full line segment.

The outputs of the assignment model were recorded as flows (volumes) of vehicles on the various roads. An attribute field for assigned traffic volumes was written to the DBF file of the road network. This field is used to establish the traffic congestion.

## **5.2 Measuring Traffic Congestion-V/C Ratio**

The volume to capacity (V/C) ratio was used to establish the congestion levels on the various roads. In order to compute the V/C ratio, the field with assigned volumes on the road network DBF file was divided by the field with the capacity of road links. The flow map files were then converted into ArcGIS shapefiles using the convert functions in flow map. The V/C ratios of the various roads were then visualised in ArcGIS as quantities in graduated colours. The V/C ratios were expressed into four classes, as shown in Table 5.3.

## **5.3 Simulation of the Effects of Traffic Congestion Mitigation Measures**

Literature review was conducted to establish the causes of traffic congestion based on global experiences. It revealed some of the causes

**Table 5.3: Classification of transport system performance based on the V/C ratio**

V/C ratio class	Description of transport system operation performance
0 - 0.850	Below capacity
0.851 – 0.950	Nearing capacity
0.951 -1.000	At capacity
Above 1.00	Over capacity

*Source: Litman and Doherty (2011)*

of traffic congestion based on the experience in Nairobi, and established traffic congestion mitigation measures with reference to international best practices. Expert opinions were also used to establish traffic congestion mitigation measures (the opinions were captured during two workshops).

Based on literature review, five (5) traffic congestion mitigation measures were selected for analysis. These were categorized into supply side and demand side measures:

Supply side oriented mitigation measures

- Increased road capacity
- Construction of bypasses and missing links

Demand side oriented mitigation measures

- Policies to promote modal shift from private car to public transport and non-motorized modes
- Land use and physical planning policies to promote multi-centric growth and development of Nairobi Metropolitan Region
- Time oriented strategies-Flexible working schedules (flexi-time)

The sixth simulation involved a combination of the supply and demand side measures. Five of the mitigation measures were simulated using the FSM methodology, while time oriented strategies were analyzed using a different approach (section 5.3.6).

### **5.3.1 Simulation 1: Increased road capacity**

The capacity on the road links was increased by 50 per cent and the V/C ratio was computed using the new increased capacity. This was undertaken in ArcGIS and did not require a model run.

### **5.3.2 Simulation 2: Construction of by passes and missing links**

The road network dataset was updated in ArcGIS by digitizing the three new bypass roads, namely: the Southern, Eastern and Northern by passes. Four missing link roads were also digitized and added to the road network dataset. Attribute data was assigned to each of the additional roads. After updating the dataset, the FSM was run in flow map using the parameters outlined in research question 1. After assignment of flows to the updated network, the V/C ratio was computed.

### **5.3.3 Simulation 3: Modal shift policies**

In order to test the effect of modal shift policies on traffic congestion, the parameters for the modal split step of the FSM were adjusted according to the following scenario assumptions for Vision 2030.

- The share of private car mode was reduced by 20 per cent through the implementation of policies to deter use of private cars, for example increase of fuel tax, increased parking fees, and controlling importation of cars, among other policies, as captured in the literature review.
- The share of public transport was increased by 20 per cent through application of policies to promote public transport, for example implementation of a safe, reliable, affordable, efficient and comfortable bus rapid transit system (BRTS) in Nairobi; implementation of a light rail transit system (LRT); improved walk ways and cycle lanes, among other measures as captured in the literature review.
- The vehicle occupancy ratio for cars was increased from 2.2 to 3 with the assumption that policies to promote private car occupancy, such as car sharing would be implemented.
- The vehicle occupancy ratio for public transport was increased from 12.5 to 25 with the assumption that the policy to license high occupancy vehicles (HOVs) for public transport in Nairobi would be implemented. Similarly, implementation of the BRTS and LRT options in Nairobi would lead to an increase in vehicle occupancy ratios.

The following formulae were used in the FSM to simulate the effects of modal shift.

$$Car\_trips(2010) = \frac{(SCORE \times (20/100))}{3} * 1.1 \quad (5.15)$$

$$Public\_transport\ trips(2010) = \frac{(SCORE \times (36/100))}{25} * 2.5 \quad (5.16)$$

After assignment of the traffic flows to the road network, the V/C ratio was computed.

#### **5.3.4 Simulation 4: Policies to promote multi-centric development of Nairobi Metropolitan Region**

The rationale of this simulation is based on smart growth principles captured in the literature review. The idea behind this option is that majority of flows in Nairobi are currently centred in the central area of the city, and there is need to spread these flows to other centres in the metropolitan region. The assumption is that this can be achieved through physical planning instruments that promote growth of other centres in the metropolitan region and also limit development in the central area of Nairobi. For example, establishment of special activity clusters in Thika, Machakos, Kiambu and Kajiado and adequately servicing them with proper infrastructure would encourage growth of these regions and help to decongest the core area of Nairobi city.

This assumption was operationalized in ArcGIS by increasing the number of productions and attractions in TAZs in areas outside the core Nairobi city boundary by 20 per cent, and decreasing the productions and attractions in TAZs in the core Nairobi city by 20 per cent. The FSM was then run in Flow Map using the updated TAZs to test for the effect of multi-centric development. After assignment, the V/C ratio was computed for links in the road network.

#### **5.3.5 Simulation 5: Cocktail of mitigation measures: Combined application of supply and demand side measures**

The rationale of this simulation was to test the effect of applying the supply and demand side mitigation measures in a combined strategy. Therefore, an FSM model run that combined all the supply and demand side strategies as captured in the preceding sections was executed in the

flow map. After assignment, the V/C ratio was computed for links in the road network.

After conducting all the five simulations, the V/C ratios were compared to the V/C ratios from the 2030 do nothing scenario obtained in research question 1. The effect of each mitigation measure was tested by calculating the difference in the V/C ratio between the do nothing scenario and the simulated scenario. From this, the average per cent reduction in congestion due to the implementation of the mitigation measure was computed. The average V/C for each mitigation measure was also computed. It should be noted that the averages are based on 17 strategic links selected for the purpose of analysis. The links are provided in Appendix IV.

### **5.3.6 Analysis of time-oriented strategies-Flexi time**

In order to analyze the potential for time oriented traffic congestion mitigation measures, namely, flexi-time, data from traffic count surveys on some selected roads was analyzed in Microsoft Excel. The dataset used was derived from the KIPPRA study on Urban Public Transport Patterns in Nairobi. The traffic counts were conducted from 7:00am up to 7:00pm between January and May on weekdays (Aligula *et al.*, 2005). The purpose of this analysis was to capture traffic behaviour on selected roads. The roads analyzed for this strategy were: Thika Road, Kiambu Road, Kenyatta Avenue, Jogoo Road, Mombasa Road, Langata Road, Ngong Road, Haile Selassie Avenue and Waiyaki Way.

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## **6. Results and Discussion**

### **6.1 Travel Demand**

#### **6.1.1 Number of trips generated: Productions and attractions**

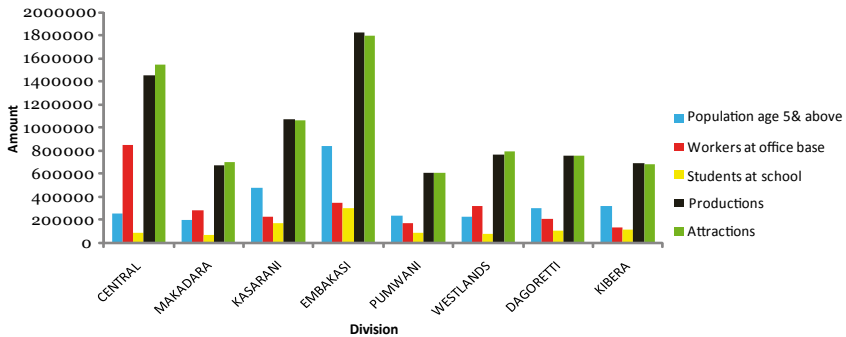
Based on the results of the FSM analysis, there were a total of 10,402,125 trips generated within NMR in 2010. It is estimated that by the year 2030, there will be a total of 25,135,351 trips generated.

The highest number of productions and attractions in Nairobi city were recorded in Embakasi Division followed by Central and Kasarani Divisions. Pumwani Division produced and attracted the lowest number of trips. It is revealed that the divisions with higher productions and attractions were also the divisions with higher numbers of the socio-economic variables. Embakasi Division had the highest population and number of students, while Kasarani Division had the second highest number of the same variables. However, Central Division had the highest number of workers and was second in terms of productions and attractions. This implies that the number of workers has a greater influence on trip generation than the population and number of students.

The results of the gravity model from flow map are stored in the form of an O-D matrix. The O-D matrix captures the flow of person trips arriving and departing to and from each TAZ. The matrix therefore captures the spatial interaction of the regions within the study area in terms of flows. From this, we can get an idea of which areas are interacting with each other and at what magnitude.

Majority of the flows (spatial interaction) in 2010 were towards the Central and North Western areas of core Nairobi city. Metropolitan areas outside the core Nairobi city depicted low levels of flows. This can be explained by the mono centric nature of development in Nairobi where most activities are concentrated in the central areas of the city. A similar observation is made in the literature review (Aligula *et al.*, 2005; CES and APEC, 2010; and Katahira and Associates International, 2006).

**Figure 6.1: Comparison of productions and attraction with socio-economic variables in NMR-2010**



### 6.1.3 Modal split: The number of public transport and private car trips

The modal split step of the FSM was conducted in flow map in order to convert person trips from the trip distribution step into vehicle trips and to split the trips/flows into public transport and private car modes. The largest number of private car O-D flows were recorded in Embakasi Division followed by Central Division then Kasarani Division. The lowest number of private car flows was recorded in Pumwani Division. In terms of public transport, the largest flows were recorded in Embakasi Division followed by Central Division, then Kasarani Division. The lowest public transport flows were found in Pumwani Division. This is explained by the fact that O-D flows correspond to the productions and attractions.

Although the probability of trip makers using private car mode was 15 per cent, it was less than the probability of using public transport, which was 36 per cent. The total private car trips stood at 780,160 and were more than public transport trips, which totalled 748,954. The reason for this result is that public transport mode has a higher vehicle occupancy rates (12.5 person trips) than private car modes of transport (2.2 person trips), hence accommodating more travellers/trips.

### 6.1.4 Traffic assignment: Number of flows on roads

The public transport and private car trips were loaded onto the road network in Flow Map. The assignment method was based on the

shortest path algorithms and assumptions mentioned in the preceding section on data analysis. A set of 17 strategic roads in the NMR road network were selected to allow for interpretation. The selected roads make up the main arteries serving the NMR.

The results of the assignment reveal that Juja Road recorded the highest number of vehicular flows (278,782), while Kiambu Road recorded the lowest number of vehicular flows (11,613). However, these results should be interpreted with consideration to the fact that capacity constraints and route switching were not considered. The weaknesses of the AON assignment method might have had influence on the number of flows recorded on the roads. This is especially true because the reality on the ground, for example, is that drivers choose to divert from Thika Road when it is congested and opt to use the alternative route of Kiambu Road in order to maximize their utility in terms of travel time and costs. It should also be noted that the road network used for modelling purposes is simplified to include only class A, B, C and D roads. Therefore, the shortest path routes used for assignment in this study may differ from the actual shortest path routes that drivers use in NMR. However, the results can be relied upon because most drivers use these major roads under normal circumstances.

Traffic volumes will increase significantly by the year 2030 in the event that no interventions are put in place. From Table 6.1 traffic volumes would increase by as much as 300 per cent on some roads with majority of the roads indicating a traffic volume increase of over 100 per cent. This increase is based on the fact that the key variables that affect trip generation, namely population size, number of students and workers would also increase by the year 2030, leading to a consequent increase in production and attraction of trips. The assumption of the do nothing scenario means that the characteristics of the road network and travel patterns would remain the same between 2010 and 2030.

## **6.2 Measuring Traffic Congestion**

Based on the analysis and computation of the V/C ratio, the road transport system performance was evaluated to determine occurrence of congestion. Table 6.1 presents the results for the year 2010 and 2030 for a subset of 17 links.

The results for 2010 indicate that majority of the roads under analysis were operating above capacity, meaning they were experiencing



**Table 6.1: Traffic congestion on selected roads in NMR: V/C ratios -2010 and 2030**

Name	V/C ratio 2010	V/C ratio 2030 (do nothing scenario)
Ngong Road	4.79	15.49
Jogoo Road	0.89	2.22
Chiromo Road	2.71	7.97
Uhuru Highway	2.71	7.97
Muranga Road	2.52	4.32
Thika Road	3.72	12.29
Limuru Road /Muthaiga Road	1.98	5.39
Magadi Road	1.88	7.86
Kiambu Road	0.46	1.96
Mombasa Road	2.60	8.57
Waiyaki Way	3.62	11.65
Forest Road	8.83	25.25
Parklands Road	4.42	12.62
Juja Road	13.94	40.05
Lang'ata Road (2 lanes )	2.21	4.87
Lang'ata Road (4 lanes )	1.64	4.98
Outer Ring Road	3.88	10.52

congestion. Juja Road presents the worst case with a V/C ratio of 13.94, while Kiambu Road was operating below the capacity with a V/C ratio of 0.46. The best performing road was Jogoo Road with a V/C ratio of 0.89, which means it was nearing capacity. The case of Kiambu Road means that it is inefficient and that the investment in terms of road construction is 'idle' and not providing the anticipated returns. The presence of congestion indicates that Nairobi is exposed to economic, social and environmental costs that arise from this situation. The situation is much worse in the year 2030 under the do nothing scenario, where congestion levels will be as high as 40 and all roads will be operating above capacity.

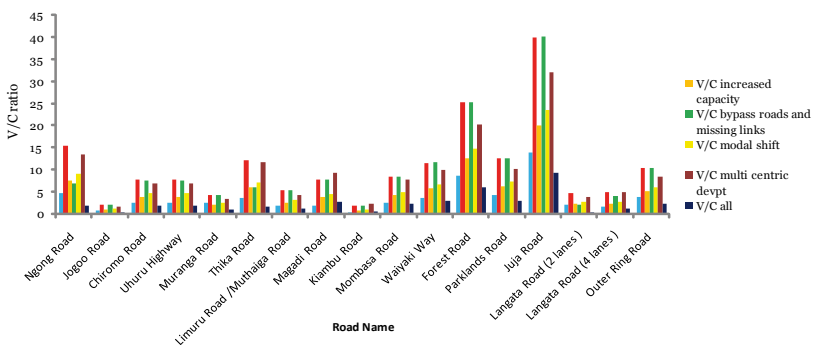
It should be noted that some roads were not assigned any flows during the assignment step and may appear as though operating below capacity. As discussed earlier, majority of the roads on the east and west of the CBD are congested.

### 6.3 Effects of Traffic Congestion Mitigation Measures

Based on literature review, four traffic congestion mitigation measures were identified for analysis. These were divided into supply and demand side oriented measures, with the rationale being to test which had the greatest effect of reducing congestion when compared to the congestion levels in the year 2030 do nothing scenario. The results are grouped together for easier interpretation and presented in Figure 6.2. Detailed results are available in Appendix V.

The results indicate that measures to increase road capacity had the greatest individual effect of reducing congestion with an average V/C ratio of 5.41 for the analyzed links. Modal shift strategies had the second best effect of reducing congestion and recorded a V/C ratio of 6.39. Construction of bypass roads and missing links recorded the least effect on reducing traffic congestion, with an average V/C of 9.72. When all the mitigation measures are combined, the effect on reducing congestion was greatest with an average V/C ratio of 2.48. It is also observed that the effect of the mitigation measures differed depending on the road. For example, construction of bypass roads and missing links performed better than increasing road capacity on Thika Road, Ngong Road and Lang'ata Road. This could be explained by the fact that the traffic dynamics differ spatially and thus mitigation measures should have a spatial distribution based on the road and characteristics of travel demand in the area. For example, the bypass on Thika Road created a diversion of traffic to a different shortest path route and thus had a greater effect on reducing congestion. It is expected that rational drivers, working with perfect information, will avoid the roads that are congested and use the alternative route created, even if the new route is longer in distance.

**Figure 6.2: Effect of traffic congestion mitigation measures on reducing the V/C ratio-2010 and 2030**



### **6.3.1 Time oriented strategies-Flexi time**

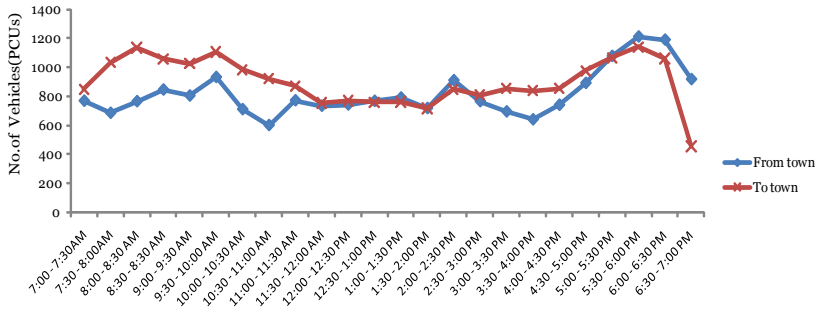
The results from the analysis of traffic counts conducted at strategic locations in Nairobi from 7:00am-7:00pm for a subset of roads in Nairobi are presented. An example of Thika Road is shown in Figure 6.3 to facilitate discussion. The results are presented in terms of peak hours of travel with the aim of identifying how traffic volumes vary with time of day and direction. Given the mono-centric nature of development in Nairobi, the central area was used as the focal and is referred to as (to town-from town) in the figure.

Based on the analysis, it is revealed that for vehicles heading to the central area (town) using Kiambu Road, Waiyaki Way, Thika Road, Magadi Road and Jogoo Road, the morning peak hours of travel were between 7:00am-8:30am in 2005, while the evening peak hours from town were between 4:30pm-6:30pm. Thika Road was an exception, indicating morning and evening peak hours of travel towards town. This temporal behaviour of traffic could be explained by the official working hours for most trip makers (workers and students), which range between 8:30am-9:00am (reporting) and 5:00pm (departing). It is, therefore, expected that majority of the trip makers will be on the road at the same time and, therefore, create the potential for congestion. It should, however, be noted that a portion of traffic would have used the road before 7:00am and after 7:00pm.

Roads within the central area, namely Kenyatta Avenue and Haile Sellasie Avenue exhibited peak traffic between 11:00am-12:30pm and 5:00pm-6:30pm in the direction towards the CBD. This could be explained by the assumption that most of these trips are for other purposes than work or school, for example business meetings and shopping. Traffic moving in the opposite direction away from the CBD towards Community area on Haile Selassie Avenue exhibited peak traffic between 8:00am-9:30am, 11:00am-12:30pm and 3:30pm-6:30pm. This could be explained by the fact that the Community area has a mixture of commercial developments and government institutions that generate trips with different schedules, but the evening peak traffic could be explained by home trips by workers from the CBD area towards Ngong Road. Traffic moving from the CBD towards Serena Hotel section of Kenyatta Avenue exhibited highest volumes between 7:30am-8:30am and 12:30pm-1:30pm. The morning peak in this section could be explained by work and school-based trips heading towards Valley Road, Hurlingham, Community and Upper hill area,

while the lunch time peak could be explained by business, shopping, lunch and other trips that are not work or school-based.

**Figure 6.3: Vehicle traffic behaviour: Volumes on Thika road from 7:00am-7:00pm**



## **7. Conclusion and Recommendations**

### **7.1 Limitations**

Several limitations were identified in undertaking this research. The main data limitations identified were in the acquisition of the relevant spatial and non-spatial datasets. The originally targeted data was not acquired and, therefore, alternatives were sought. The alternatives involved compilation of a new dataset from various sources such as census records and other available datasets. Some of the data used had to be computed, and this might have generated inaccuracies. For instance, the road network spatial dataset indicated some topological errors. The traffic count data used to capture time oriented mitigation measures was based on the year 2005.

The main technical and methodological limitations identified were in the choice of software application used to execute the FSM. Flow map is known to use the AON assignment technique, which has some assumptions that are incongruent with reality. The application is also static, meaning that it cannot capture the temporal aspects of travel behaviour. However, a combination of the model with MS Excel helped to improve the results.

### **7.2 Conclusion**

This research set out to evaluate the effectiveness of road traffic congestion mitigation measures in the NMR. The aim was to establish strategic options that could be used to mitigate the problem of road traffic congestion. Literature review provided an insight to the definitions, concepts and theories that explain road traffic congestion as well as provide a background to its causes and effects. Various traffic congestion mitigation measures were identified based on review of studies from different countries around the world. Some best practices/ win-win strategies were also noted. A review of the urban transport system in NMR was conducted and the literature revealed that the problem of traffic congestion is rampant in the region. Contemporary mitigation measures that have been proposed or implemented to tackle traffic congestion in NMR were identified as well as the actors responsible.

Results from the FSM simulation and data analysis revealed that in 2010, the major roads serving the NMR were congested. It also emerged that the situation would be significantly worse by the year 2030, if no measures were taken to address traffic congestion. Traffic congestion in Nairobi was seen to be influenced by both demand and supply side factors, leading to a high number of trip productions and attractions. The road capacity available was not sufficient to serve the traffic volumes generated. It also emerged that majority of traffic flows were concentrated in the central area of Nairobi city, leading to congestion on the primary radial roads that provide access to the central area of Nairobi.

Five traffic congestion mitigation measures were selected for analysis in order to simulate their effect on reducing congestion. Time-oriented traffic congestion mitigation measures were also explored. On the supply side, the capacity of roads was doubled as well as addition of bypass roads and missing link roads to the model road network. On the demand side, two simulations were conducted, the first was on modal shift strategies, which increased the share of public transport and reduced the share of private car mode of transport, as well as increasing the vehicle occupancy of both modes. The second was on strategies to promote multi-centric development of the NMR with the aim of redistributing the concentration of traffic flows away from the central area of Nairobi city. A final simulation was done, which combined all the four mitigation measures. It emerged that increasing road capacity had the greatest effect on reducing congestion, second was implementation of the modal shift strategies, and third was building bypass roads and missing links, while implementation of multi-centric development of the NMR was fourth. A combination of all mitigation measures yielded a significant reduction in road traffic congestion. It was observed that traffic flows on the major roads in Nairobi city followed a temporal pattern of high flows that coincided with hours in which most work trips and home trips were executed.

Both demand side and supply side measures have significant effect on reducing road traffic congestion. The current practice in regard to traffic congestion mitigation in the NMR has placed more emphasis on the supply side, while demand side and time oriented strategies have been less prominent. Finally, readers are advised to recognize the limitations of this research when drawing further conclusions.

## **7.3 Recommendations**

### **Demand side measures**

Policies to promote multi-centric development of the NMR should be implemented. This can be done through application of smart growth land use development strategies in the major towns in the NMR. Smart growth strategies entail mixed use, compact and high density settlements based on the concept that homes are in close proximity to working places, social services and recreation facilities. These outlying centres should be made attractive through provision of world class infrastructure and economic services.

The number of trip productions and attractions should be controlled with the aim of achieving sustainable levels in relation to the road network capacity. Strategies to address this include smart growth development and telecommuting, among others.

It is also recommended that the amount of automobile travel generated, irrespective of roadway capacity, should be adopted as a new indicator to measure transport system performance in order to capture the demand side.

### **Supply side measures**

Enhancement of non-motorized transport (NMT) would further support the modal shift strategies. Segregated NMT paths should be provided as a compulsory component of the road network. Incentives such as right of way (ROW), priority access, pedestrianization of streets in the CBD and a salary allowance for NMT users should be provided to further encourage its uptake. The NMT system should be integrated with other systems in a comprehensive multi-modal network.

Intersection management strategies should be implemented for the newly constructed missing link roads and bypass roads so as to avoid interruption of traffic flows on the existing roads.

Higher vehicle occupancy rates should be promoted through such strategies as car-pooling, car sharing and licensing of high occupancy public service vehicles. Increased use of commuter rail services would also reduce road traffic congestion.

### **Beyond space, towards time**

Time-oriented strategies such as flexi-time should be implemented in the NMR. Both public and private sector should be encouraged to implement this policy. Implementation of policies that promote a 24-hr economy in the NMR would complement the flexi-time strategies. It should be noted that enhancing 24hr security and providing a reliable public transport system would also complement flexi-time strategies.

### **Appropriate mix and sequencing of traffic congestion mitigation measures**

Traffic congestion mitigation measures should be implemented in an integrated demand and supply side strategy in the NMR. The mitigation measures should vary depending on the prevailing traffic dynamics of a particular road or traffic zone. Consequently, institutions charged with the responsibility of physical planning, road and transport planning should integrate their activities and adopt a coordinated approach in executing their functions. These institutions should adopt a common policy and strategy aimed at mitigating traffic congestion. A special agency such as the Metropolitan Development Authority can be charged with the responsibility of coordinating integration of land use and transport planning.

Increasing the capacity of roads, constructing bypass roads and missing link roads should be implemented together with policies that increase the share of public transport, while reducing the share of private car modes of transport. Strategic implementation should ensure that a reliable, safe, efficient, and comfortable public transport system is first set in place to attract more ridership. This should then be followed by a combination of carrot and stick strategies aimed at shifting potential private car trips into the public transport system. It is, however, important to ensure that before punitive instruments are implemented to discourage ownership and use of private cars, appropriate public transport and travel demand management instruments are first provided.

### **Policy focus**

Policies should focus on providing reliable and predictable travel times as well as efficient travel speeds. To achieve this, public transport



should be segregated from private transport modes through creation of dedicated public transport lanes on the roads. These would enable the implementation and adherence to public transport time schedules, which would then ensure reliability and predictability of public transport services. In addition, constant surveillance of the road system and prompt response to incidents that interfere with traffic flow will be necessary. Application of intelligent transport systems (ITS) would go a long way in achieving predictability of travel.

The use of social media in enhancing predictable travel times should also be pursued. A traffic control centre should therefore be created to acquire, process and disseminate real-time traffic conditions using multimedia avenues. The output can also be used for dynamic traffic light sequencing. Traffic cameras are already in place in Nairobi. The public sector should thus partner with the private sector and apply the digital data for the traffic control centre. The surveillance systems should further be used to identify and apprehend traffic offenders. These would also act as deterrents to indiscipline, and reinforce positive road user behaviour.

#### **7.4 Further Research**

Further research should be undertaken to determine:

- (a) The traffic behaviour in the NMR using dynamic travel demand modelling applications.
- (b) The cost-benefit analysis of the different traffic congestion mitigation measures addressed in this study. Other mitigations measures should also be studied.
- (c) The amount of freight currently using road transport and the impact of diverting this freight towards rail transport.
- (d) The actual economic, social and environmental impact of road traffic congestion in the NMR. In particular, computing the economic cost of congestion, the impacts of congestion on health and welfare and the contribution of congestion to climate change through emission of greenhouse gases.

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## Appendix

### Appendix I: Statutory and regulatory framework of the transport sector in Kenya

Description		Statutes and Regulations
Over-arching statutes		The Constitution of Kenya
		The Kenya Police Act
		The Administration Police Act
		The Way leaves Act, Cap 292
		The Environment and Management Coordination Act 1999
		The Kenya Revenue Authority Act
		The Insurance Act
		The Exchequer and Audit Act, Cap 412
		Privatization Act 2005
		Public Procurement and Disposal Act 2005
		Public Private Partnership Act
		Lake Basin Development Act
Sector specific	Rail transport	The Kenya Railways Corporation Act, Cap 397 The East Africa Inland Water Transport Act
	Pipeline transport	The Petroleum (Exploration and Production) Act, Cap 308
	Air transport	The Kenya Airports Authority Act, Cap 395 The Civil Aviation Act, Cap 394 The Carriage Air Act No. 2 of 1993 International Civil Aviation Convention 1944 (hereinafter referred to as The Chicago Convention)
	Shipping, maritime and inland waterways transport	Kenya Maritime Authority Act 2006 Kenya Ports Authority Act, Cap 391 The Carriage of Goods by Sea Act, Cap 392 The Fisheries Act, Cap 378 Lake Victoria Act 2007 The Merchant Shipping Act No. 4 of 2009 The Ferries Ordinance Act, Cap 410 The Marine Insurance, Cap 390 The Mtwapa Bridge Act, Cap 402 The Judicature Act, Cap 8 Various regional/international maritime legal instruments
	Road transport	The Transport Licensing Act, Cap 404 The Kenya Road Boards Act, Cap 408 The Roads Maintenance Levy Fund Act No. 9 of 1993 as amended in 1994 The Public Roads Toll Act, Cap 407 The Finance 2005 Act The Public Roads and Roads of Access Act, Cap 309 The Local Government Act, Cap 265 The Kenya Roads Act No. 2 of 2007 The Traffic Act, Cap 403 The Streets Adoption Act, Cap 406 The Valuation of Rating Act, Cap 266 The Rating Act, Cap 267 The Wildlife Conservation and Management Act, Cap 376 The Central Road Authority Act The Local Authorities Transfer Fund Act No. 6 of 1996 The Agriculture Act, Cap 318 The Physical Planning Act No. 6 of 1996 The Local Authority Service Charge Act, Cap 274

Source: Sessional paper on integrated national transport policy 2010

**Appendix II: Win-win transportation solutions and their application in NMR**

<b>Traffic mitigation measure</b>	<b>Description</b>	<b>Impacts</b>	<b>Application in Nairobi (Yes /No)</b>	<b>Actor</b>
Least-cost planning	More comprehensive and neutral planning and investment practices	Increases investment and support for alternative modes and mobility management, improving transport options	Yes	MoNMD
Mobility management programmes	Local and regional programmes that support and encourage use of alternative modes	Increases use of alternative modes	Yes	MoNMD; MoT; KURA; KeNHA; CCN
Mobility management marketing	Improved information and encouragement of transport options	Encourages shifts to alternative modes	No	-
Transport infrastructure expansion	Expansion of existing roads, building of new roads, design improvements	Increases capacity	Yes	MoNMD; MoT; KURA; KeNHA; CCN
Commute trip reduction	Programmes by employers to encourage alternative commuter options	Reduces automobile commute travel	No	-
Commuter financial incentives	Offers commuters financial incentives for using alternative modes	Encourages use of alternative commuter mode	No	-
Fuel taxes-tax shifting	Increases fuel taxes and other vehicle taxes	Reduces vehicle fuel consumption and mileage	No	-
Pay-as-you-drive pricing	Converts fixed vehicle charges into mileage-based fee	Reduces vehicle mileage	No	-

Road pricing	Charges users directly for road use, with rates that reflect costs imposed	Reduces vehicle mileage, particularly under congested condition	Yes	KeNHA
Parking management and pricing	Various strategies that result in more efficient use of parking facilities and charges users directly for parking facility use, often with variable rates	Reduces parking demand and facility costs, and encourages use of alternative modes	Yes	CCN
Transit and ride share improvements	Improves transit and ride share service	Increases transit use, van pooling and car pooling	No	-
Flexitime	Flexible work schedules with a variety in work reporting and closing times	Reduces peak time traffic congestion	Yes	MoNMD
High Occupancy Vehicle priority	Improves transit and ride share speed and convenience	Increases transit and ride share use, particularly in congested condition	Yes	MoT
Walking and cycling improvements	Improves walking and cycling condition	Encourages use of non-motorized modes, and supports transit and smart growth	Yes	MoNMD; MoT; KURA; KeNHA; CCN
Smart growth policies	More accessible, multi-modal land use development patterns	Reduces automobile use and trip distances, and increases use of alternative modes	No	-
Location efficient housing and mortgages	Encourage businesses and households to choose more accessible locations	Reduces automobile use and trip distances, and increases use of alternative modes	No	-

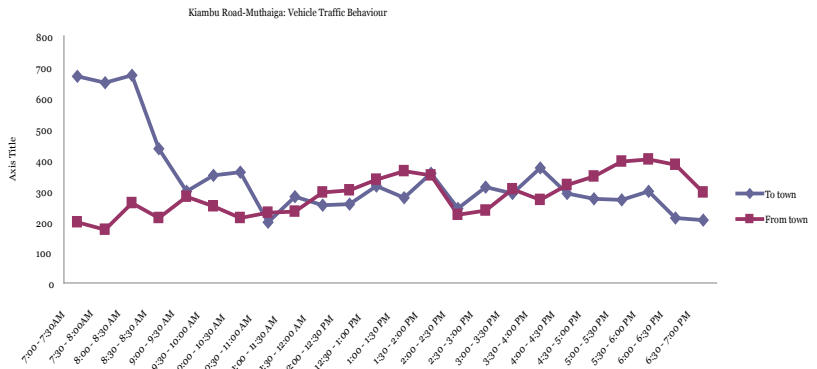
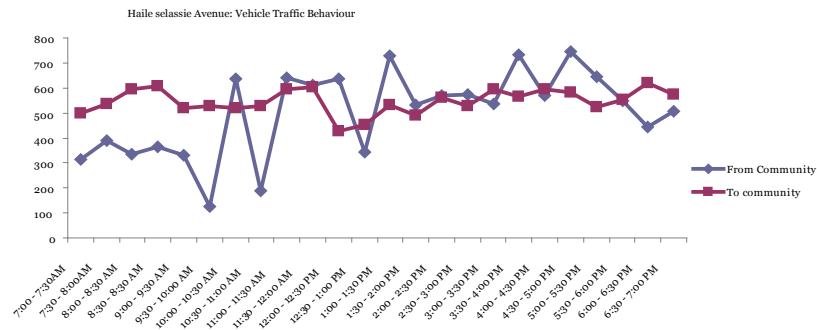
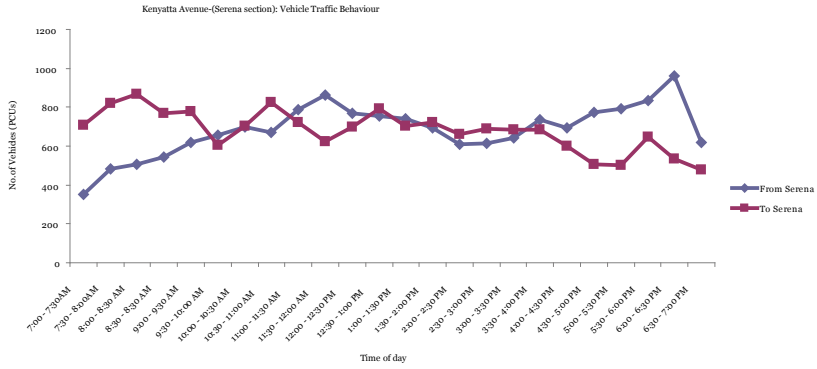
Freight transport management	Encourages businesses to use more efficient transportation options	Reduces truck transport	No	-
School and campus trip management	Encourages parents and students to use alternative modes for school commutes	Reduces driving and increases use of alternative modes by parents and children	Yes	MoNMD
Regulatory reforms	Reduces barriers to transportation and land use innovation	Improves travel options	Yes	MoT
Car sharing/ car pooling	Vehicle rental services that substitute for private automobile ownership and neighbours or workmates using one car	Reduces automobile ownership and use	No	-
Traffic calming and traffic management	Roadway designs that reduce vehicle traffic volumes and speed	Reduces driving, improves walking and cycling conditions	Yes	MoNMD; CCN
Intelligent Transport Systems (ITS), social media, remote traffic sensors	Systems to control traffic and signalling. Web and mobile technology to provide real time traffic conditions	Optimum signalling sequence at intersections and from real time traffic information trip makers can optimize their journey in advance	Yes	Access Kenya traffic cameras; Traffic updates by radio stations

*Source: Litman (2003)*

**Appendix III: Information and data needs of the FSM**

<b>Step</b>	<b>Model</b>	<b>Inputs</b>	<b>Output</b>	<b>Information / Data needs</b>
Trip generation	Multiple regression models Cross-classification Trip rate analysis	Socio-economic and land use data such as population, employment, students, car ownership, etc., presented in TAZs Parameters for model Trip rates	Prediction of the number of trips each household makes as a function of its characteristics and the number of trips attracted to a zone as a function of the zone's characteristics	KIPPRA/JICA / CES and APEC model Land use-socio economic data Calibration reports
Trip distribution	Gravity model with generalized cost function Growth-factor update	Zonal productions and attractions from the step above Gravity model parameters	Prediction of origin-destination flows, i.e., the linking of the trip ends predicted by the trip generation model together to form trip interchanges or flows (person trips)	KIPPRA/JICA / CES and APEC model Calibration reports
Modal split	Direct-demand model Trip interchange models Logit-models	O-D matrix from the step above Model parameters based on travel behaviour Modal split ratios	Prediction of the percentages of travel demand that will use each of the available modes between each origin destination path (vehicle trips)	KIPPRA/JICA / CES and APEC model Calibration report
Assignment	All-or-nothing User-equilibrium modelling Social-equilibrium modelling Macroscopic traffic assignment	O-D matrix by mode form above; Multi-modal; Transport network; Vehicle occupancy rates	Assignment of the modal O/D flows on specific routes of travel through the respective modal network (using shortest paths)	KIPPRA/JICA / CES and APEC model Calibration report Transport network in Nairobi

### Appendix IV: Time-oriented strategies-behaviour of traffic volumes on roads according to time



**Appendix V: Effects of the traffic congestion mitigation measures on reduction of the V/C ratio on selected roads**

Road name	V/C 2010	V/C 2030 do nothing	V/C increased capacity	V/C bypass roads and missing links	V/C modal shift	V/C multi centric devpt	V/Call
Ngong Road	4.79	15.49	7.75	6.92	9.15	13.53	1.97
Jogoo Road	0.89	2.22	1.11	2.22	1.31	1.78	0.53
Chiromo Road	2.71	7.97	3.98	7.61	4.71	7.02	2.02
Uhuru Highway	2.71	7.97	3.98	7.61	4.71	7.02	2.02
Muranga Road	2.52	4.32	2.16	4.34	2.56	3.47	1.03
Thika Road	3.72	12.29	6.14	6.04	7.26	11.71	1.66
Limuru Road/ Muthaiga Road	1.98	5.39	2.69	5.39	3.18	4.31	1.27
Magadi Road	1.88	7.86	3.93	7.86	4.65	9.45	2.79
Kiambu Road	0.46	1.96	0.98	1.96	1.16	2.35	0.70
Mombasa Road	2.60	8.57	4.28	8.56	5.06	7.79	2.30
Waiyaki Way	3.62	11.65	5.83	11.75	6.88	10.12	3.02
Forest Road	8.83	25.25	12.62	25.35	14.92	20.33	6.05
Parklands Road	4.42	12.62	6.31	12.67	7.46	10.17	3.02
Juja Road	13.94	40.05	20.02	40.14	23.66	32.01	9.49
Lang'ata Road (2 lanes)	2.21	4.87	2.44	2.29	2.88	3.89	0.54
Lang'ata Road (4 lanes)	1.64	4.98	2.49	4.06	2.94	4.97	1.28
Outer ring Road	3.88	10.52	5.26	10.52	6.22	8.43	2.49
Average	3.70	10.82	5.41	9.72	6.39	9.31	2.48





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