

A SMART TRAFFIC MANAGEMENT SYSTEM

BY

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FULFILLMENT OF THE REQUIREMENTS FOR THE
AWARD OF MASTERS OF SCIENCE IN DATA
COMMUNICATIONS IN THE FACULTY OF COMPUTING
AND INFORMATION MANAGEMENT
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DECLARATION

I declare that this Research project is my original work and has not been previously published or submitted elsewhere for award of a degree. I also declare that this Research project contains no material written or published by other people except where due reference is made and author duly acknowledged.

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I do hereby confirm that I have examined the master's Research project of

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AND have certified that all revisions that the Research project panel and examiners recommended have been adequately addressed.

Sign: _____ Date: _____

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ABSTRACT

The problem of traffic congestion and difficulties in management of road networks has been a major concern in many countries. The countries have addressed these problems using a myriad of solutions. The use of ICT to manage road networks has been fronted as one of the best solutions and great strides have been made in various countries to utilize it in road traffic management.

My research looks at how ICT has been utilized to manage the various transport systems and offer a variety of services to end users, more particularly in the area of traffic management and mitigation of traffic congestion especially in the developed world.

Various systems have been employed for example the adaptive traffic lights that change based on an analysis of the existing real time traffic information, collision avoidance systems, weather warning systems, traffic information for train and subway systems in the UK and China, route guidance systems for route selection using GPS systems for example tom tom systems for optimal route selection in south Africa, car tracking systems are also used by companies to manage fleets. Various technologies, software and hardware that are employed in these systems have also been analyzed.

Most of these systems function independently and lack an interactive platform where data can be acquired and received freely from both parties. Therefore my research aims to integrate these systems by providing suitable interfaces and having a central databases from which better utility of the data can be achieved. Better data capture platforms and dissemination methods will be researched on and their utilization in a number of key systems in transport management will be evaluated with an aim of coming up with an integrated intelligent transport management system capable of offering a number of services to end users in the most convenient way possible.

The research has addressed the integration of traffic information collection mechanisms and the management of a central database capable of running various applications to offer different functionalities such as incident management, traffic analysis and management, weather warning system.

DEDICATION

I dedicate this work to my loving parents Joseph Masinga Nyandiri and Rebecca Bosibori Masinga and my wife Lydia who have given me physical ,moral and emotional support through which I was able to produce this work. I shall forever remain grateful to them.

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I give glory and honour to the Almighty God for giving me the ability to diligently pursue this work. I also extend my gratitude to the KCA university administration, the Graduate school, Faculty of computing and information management through whose contribution this work become a success.

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LIST OF ABBREVIATIONS

ICT----- Information and Communication Technology

OECD--- Organization for Economic and Development

RFID-----Radio Frequency Identification

CCTV----Closed Circuit Television

DSRC-----Dedicated Short Range Communication

ASTM----American Society for Testing and Materials.

OBU-----On Board Unit

RSU-----Road Side Unit

GIS-----Geographical Information System

HTTP----Hyper Text Transfer Protocol

FDMA----Frequency Division Multiple Access

API----- Application Programming Interface.

ISM-----Industrial, Scientific and Medical.

CHAPTER ONE

1. INTRODUCTION

1.1. The transport sector plays a key role in the economic and social development of a nation. This therefore calls for its regulation to ensure it functions efficiently through improvement of its infrastructure to improve efficiency and offer new services to the users. The use of ICT to improve the functioning of the transport network is the key to unlocking its potential for economic development as Stephen Ezell ,2010 affirms "the future of transport lies not only in concrete and steel but also increasing in using ICT".

1.2. BACKGROUND INFORMATION

1.2.1. There has been increased urbanization accompanied by industrialization in both the developed and the developing world as well. This has led to a proliferation of motorized transport especially in the developed world resulting in road traffic congestion. This congestion reduces road traffic efficiency, increases time of travel, fuel consumption and stress levels in commuters, the emission levels also go up thereby occasioning environmental degradation. This in turn will negatively impact on economic growth. According to M. Meyer et al (1989) in the institute of transportation Engineers Journal , billions of hours are wasted each year in traffic jams."Jams not only impede mobility but also pollute air, waste fuel and hamper economic growth" pg ix. According to Nairobi metropolitan region traffic decongestion program report, Kenya loses approximately kshs 30 billion daily on lost fuel, stress, time and environmental degradation.

1.2.2. The 2011 tomtom traffic survey in South Africa states that 78% of 3.8 million drivers in Johannesburg roads are stuck in a severe traffic jam on a daily basis. According to Lam Jian et al (2012) traffic jams are part of Malaysia's city life. According to OECD Journal,2007, nearly 20% of national income is spent on transport, road accidents account for 2% of deaths in the UK therefore road traffic has got both economic and safety implications. Road traffic jams continue to be a major problem in most cities around the world and especially in developing regions resulting in massive delays, increased fuel wastage and monetary losses. (Road management and engineering journal,transafety Inc 1998).

1.2.3. To mitigate this problem most governments have put in place various measures using ICT to replace or augment traditional methods of traffic control like infrastructure expansion, traffic lights and legislation on speed limits. The EU and the U S have focused on the use of intelligent transport system (ITS) to improve the road transport performance in addition to providing homeland security(Wikipedia encyclopedia October 2012).The ITS combine various technologies to monitor, report and manage the transport network. These technologies include various wireless communication systems, collision avoidance systems and cooperative systems incorporated with various RFID, Bluetooth or GPS technologies for communication.

According to ITE journal 2012, The US uses a detector system connected to a central computer to monitor freeways and provide pertinent information through changeable message sign system and radio traffic reports (ITE journal pg 20).

1.2.4. The information for motorists (INFORM) Project in Newyork gives real time traffic information to motorists. According to A. bein (2012) The UK has a national traffic control centre (NTCC) which monitors the road network using CCTV and traffic sensors 24/7. They use the Active Traffic Management system which can implement variable speed limits based on real time traffic information. South Africa uses Tomtom HD traffic navigation systems for route guidance to reach destinations faster. China is implementing STAR WINGS project which is an information system for traffic management and best route selection.

1.3. DEFINITION OF KEY TERMS

1.3.1. **Simulation.** This generally refers to a computerized version of the model which is run over time to study the implications of the defined interactions. A simulation is the manipulation of a model in such a way that it operates on time or space to compress it, thus enabling one to perceive the interactions that would not otherwise be apparent because of their separation in time or space.

1.3.2. **System.** A system exists and operates in time and space. A system is understood to be an entity which maintains its existence through the interaction of its parts.

1.3.3. **Model.** A model is a simplified representation of a system at some particular point in time or space intended to promote understanding of the real system. A model is a simplified representation of the actual system intended to promote understanding.

1.3.4. **Telematics.** This is the integrated use of telecommunications and informatics, also known as ICT (Information and Communications Technology).

1.3.5. **Probe vehicle.** This is a vehicle that is equipped with a communication device so as to relay its speed, location and other traffic information to a central location from where it will be utilized.

1.3.6. **Spatial aggregation.** This is a type of data processing where received data is averaged in terms of space so as to derive meaningful processing especially where there are quick changes to data over a given length.

- 1.3.7. **Temporal aggregation.** This is a type of data processing where received data is averaged in terms of time so as to derive meaningful processing especially where there is quick changes to data over a given time span.
- 1.3.8. **Bluetooth technology.** This is a form of wireless communication whereby devices exchange data over short distances using radio waves within the ISM band. It is standardized under IEEE 802.15.1 Standards.
- 1.3.9. **RFID Technology.** This is Radio Frequency Identification Technology whereby tags with magnetic fields are used to exchange information with readers usually over short distances.
- 1.3.10. **Geographical information system.** This is a system that collects and stores geographical information that can later be used for analysis and decision making in a system. Most of these systems utilize the GPS system.

1.4. PROBLEM STATEMENT.

1.4.1. Whereas most of the countries in the developed world have tried to use ICT in traffic management, the applications and devices used are not integrated to a central system with a complete package to offer a wide range of services to cater for vehicle users, pedestrians and prospective passengers by allowing flow of interactive and real time traffic information.

1.4.2. My research will focus on ways to centralize the traffic information processing from various equipments and sources with a view to providing better processing, interpretation and dissemination, this will in turn translate to improved transport system performance and increased number of services that can be offered through the intelligent networks.

1.4.3. It will also try to improve the level of interaction between the transport system user and system control in real time by increased input /output terminals, more transponders, increased blogging and traffic information broadcasts.

1.5. STUDY OBJECTIVES

AIM OF THE RESEARCH

1.5.1. To explore the existing transport management systems and develop a smart road traffic management system.

1.5.2. OBJECTIVES OF THE RESEARCH

- a. To identify sample intelligent transport management systems and other information and communication technologies used in the transport sector.
- b. To identify the various advantages, disadvantages and shortcomings of similar systems in sample countries where the systems have been used.
- c. To identify the most suitable ICTs to use in sample roads for the transport management system.
- d. To design an integrated system for managing the road transport network.
- e. To test and validate the integrated transport management system.

1.5.3. RESEARCH QUESTIONS.

- a. What are the existing transport management systems that are currently in use and how effective are they?
- b. Can the use of ICT in the transport management system improve efficiency?
- c. How can the various transport management systems be integrated so as to be centrally managed to produce better results?

1.6. IMPORTANCE OF THE RESEARCH

1.6.1. It brings improvement in transport system performance through reduction of traffic congestion, increased safety and traveler convenience. It will therefore optimize the use of available road network and the kind of resources that are committed to transport

1.6.2. It will lead to improvement of the environment through reduction of harmful emissions, it will also cut on fuel wastage and travel time hence this will spur economic growth.

1.6.3. There will be improved national safety and security due to constant 24 hour surveillance and information on all activities on the roads. There will be collision avoidance systems, cooperative systems, weather warning systems and emergency call systems on the roads with requisite communication systems to relay the information to the relevant call centres or to broad cast outlets.

1.6.4. Increased availability of transport information and interactivity will greatly improve commuters' convenience and lead to better travel decision making. This will in turn make travelling a better experience hence reduced stress levels, better and longer lives.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. STATE OF THE ART.

2.1.1. **DATA COLLECTION METHODS.** Various methods have been used previously to count traffic from the use of manual means where observers were used to give the traffic trends and statistics up to the use inductive loop detectors which can give traffic counts electronically but they are still not sufficient. Traffic count techniques can be either intrusive or non intrusive.

- a. **Intrusive methods.** Intrusive methods are ones which involve placing a data recorder and sensor on or in the road. They are embedded in the road infrastructure and there repair and maintenance may disrupt road use when it is being carried out. Some of the methods are as shown below:
 - **Pneumatic road tubes.** These are devices that use pressure as a means to measure traffic count. They are placed across road lanes and they detect vehicles through the pressure changes produced when vehicles pass through them. Their disadvantages are limited coverage and their efficiency is subject to weather and traffic conditions. Low speeds may not be accurately measured.
 - **Inductive magnetic loops.** They are embedded on roadways in a square formation to create a magnetic field .Vehicles will be detected when they cross this magnetic field thus recording a count which will be transmitted to a counting device place on the side of the road. Modern loop detectors have the ability to convert the data into formats that are compatible with other devices in the network.
 - A lot of effort has been put to this area and it is now considered a mature technology since there are so many manufacturers of the detectors and a lot of improvement to an extent that some detectors can be able to do minor analysis like aggregation and conversion to compatible data formats so as to prepare it for transmission.
 - The spacing of the detectors is normally determined based upon the level of accuracy required with a reasonable distance of 2-5 km being ideal. Too close or too far apart may not give accurate results.

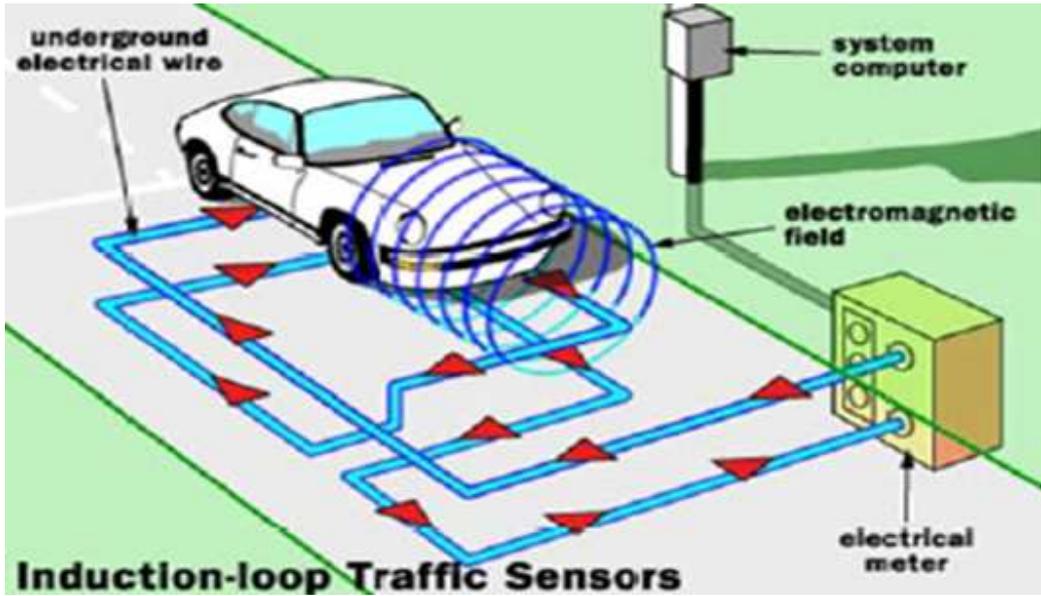


Figure 2.1. How an inductive loop detector works.

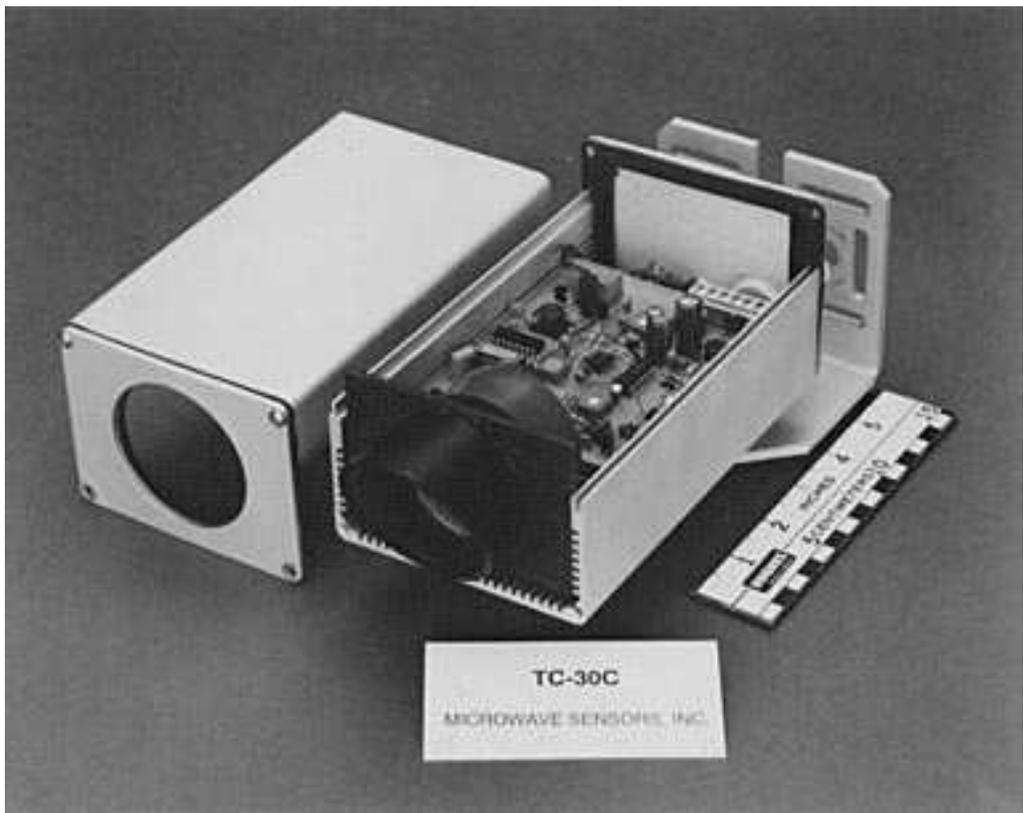


Figure 2.2.A TC-30C type inductive loop detector

Advantages

- This device is not affected by weather conditions
- It has no car positioning errors since it is normally static and its location is known.
- It gives accurate traffic flow and speed measurement.
- It is an established technology which makes it more reliable since it has been tested by various vendors and users.

Disadvantages

- They are expensive to install and maintain.
- They have limited coverage.

b. **Non intrusive methods.** These are methods that are based on remote observations, they are not embedded in the road infrastructure and they may not interfere with road usage during repair or maintenance. Some of these methods include:

- Manual counts
- Passive and active infra red
- Microwave radars-they can detect vehicles speed using the Doppler effect
- Ultra sonic and passive acoustic devices-these devices emit sound waves and use the time taken for the signal to return so as to determine vehicle counts and speeds.

Their main disadvantage is that they are affected by bad weather.

- Video image detection. This involves use of video cameras to record vehicle numbers and speeds using trip line and tracking technique. Some intelligent cameras can be able to give number plate identification capability. Video images can be captures using CCTV and then relayed to a central facility for analysis and processing.

2.1.2. **PROBE VEHICLE TECHNOLOGY/FLOATING CAR DATA.** This is a technology that utilizes some vehicles that have been identified to collect and also to disseminate traffic information. These vehicles ply through the highways normally like any other vehicle but they are fitted with communication devices to enable them to relay the traffic information to a central facility.

- The vehicles can belong to the transport management centre or they can belong to volunteers. For example the use of taxis in Japan for the VICS system.
- This method collects real time traffic data using GPS and cellular communication means. The GPS receiver is located inside the probe vehicle to give location and speed information of the vehicle. This information is sent to a central processing unit and later disseminated to other users. The probe vehicle can also have a cell phone for tracking and sending of information.
- Probe vehicle technology can be achieved through a number of ways i.e.
 - a. Signpost based automatic vehicle location .This involves communication between transmitters mounted on existing sign post structures and probe vehicles. It has the following components :
 - Electronic transmitters
 - In vehicle receivers
 - Vehicle odometer sensor
 - In vehicle radio transmitters
 - In vehicle locating unit and microprocessor
 - Central control facility

HOW IT WORKS

The sign post emit unique identification codes which are received and interpreted by the approaching vehicle.

The sign post ID is stored in the vehicle locating unit and then assigned a time and date stamp. The corresponding odometer reading between sequential signposts and vehicle ID .This is sent to a control facility at periodic intervals or upon control's prompt

b. GPS and cellular means. This gives high precision location of a vehicle up to less than 10m. The mobile phone position is regularly transmitted to the network by means of triangulation or other techniques and the travel time and speed can then be estimated. This may involve integration with existing GIS system to extrapolate the information to section or complete road networks.

c. Automatic vehicle identifier-using electronic transponders and tags.

The RSU captures the probe vehicle ID when it enters its range and assigns a time and date stamp and also the antenna stamp. The data is transmitted to a central facility via a telephone line and then processed and stored.

Probe vehicle travel time is calculated as the difference between the time stamps at sequential antenna locations.

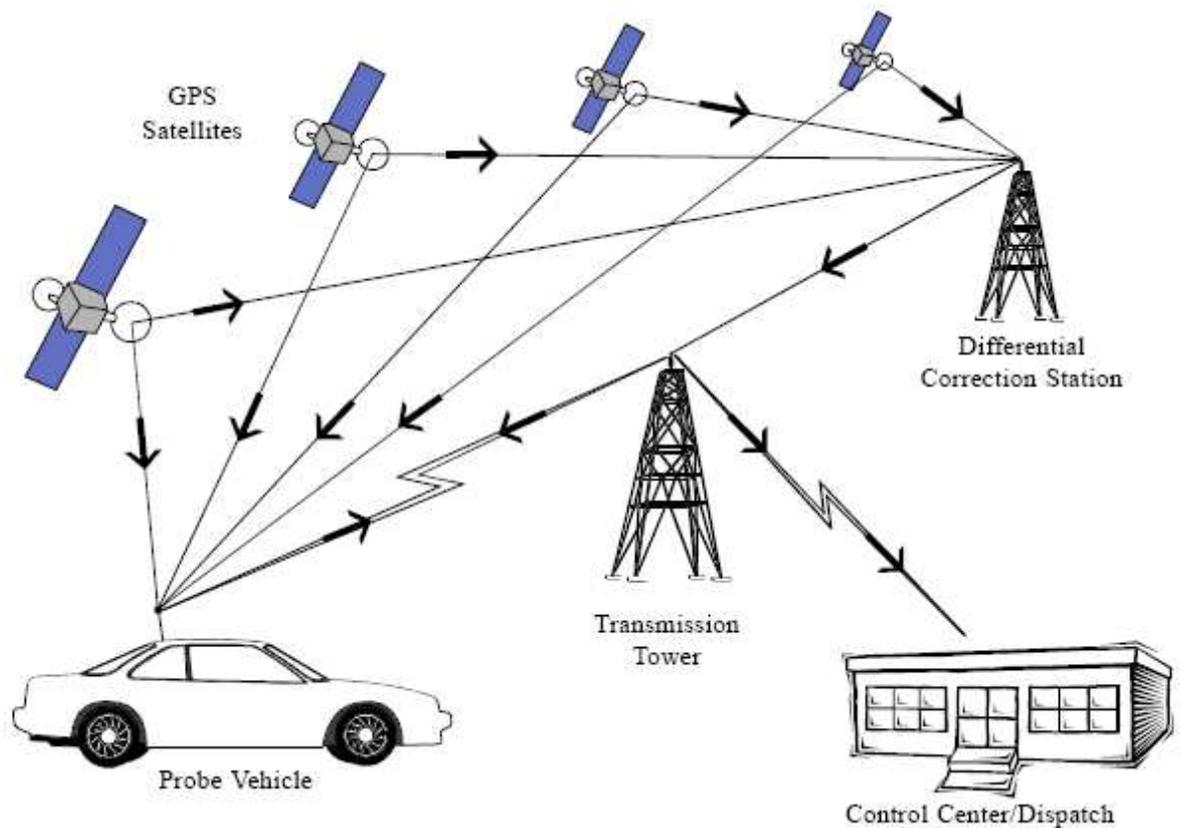


Fig 2.3. Probe vehicle system

Probe vehicles advantages.

- It requires no special devices or infrastructure to be installed on the car or road therefore it is less expensive than conventional detectors.
- Traffic data is obtained continuously hence more reliable and accurate.
- It is faster to set up, easier to install and needs less maintenance.
- It has automated data collection in formats which are compatible with other devices in the network
- There is no disruption of traffic during operation or during repair and maintenance.

Probe vehicles disadvantages

- Needs sophisticated algorithms to extract and process the data.
- It has limited sample size.
- It involves high initial implementation costs.
- It has fixed infrastructure constraints
- Privacy issues since the probe vehicle position and movement is monitored by a central facility hence the operators may feel like their privacy is compromised.

2.2. STATE OF PRACTICE.

2.2.1. DATA TRANSMISSION MECHANISMS.

a. WIRELESS ACCESS IN VEHICULAR ENVIRONMENTS (WAVE)/DEDICATED SHORT RANGE COMMUNICATION (DSRC)

- It is a mode of operation that uses the IEEE 802.11p standards of 2010 to operate vehicle to vehicle communication devices.
- It defines vehicle to vehicle and vehicle to infrastructure communications protocols for high speed data transfers and it addresses the challenges at the physical level.
- This protocol was build on top of the previous version which was ASTM E2213-03 standard.

➤ It is also based on a higher standard which is IEEE 1609 which provides for ubiquitous vehicle communication among different automobile vendors and manufacturers. This protocol addresses all aspects for communication as follows

- i. IEEE 1609.1 for resource management. It identifies key components and communication format in terms of command message and data storage format.
- ii. IEEE1609.2 addresses security issues e.g. secure message transfer formats
- iii. IEEE 1609.3.This is the network protocol layer which handles issues like routing and other network issues.

➤ Dedicated Short Range Communication (DSRC) is used for this standards which has the following properties:

- i. It is a frequency range of 5.8-5.9 GHZ, which is allotted to ITS communications.
- ii. It is short range of up to a maximum of 1000m.It has high data rates of 6-27 Mbps.
- iii. It provides half duplex communication with seven channels for both vehicles to roadside and vehicle to vehicle communications. It allocates channels such that two channels are allocated for extended data transfer, two for special safety critical applications which are accorded priority over the others.

HOW IT WORKS

➤ RSU announces to OBUs 10 times per second the applications it supports and on which channels. The OBUs listens on channel 172, authenticates the RSU digital signature then executes safety applications first before the non safety ones.

➤ This system supports the IPV6 protocol stack, it also provides for authentication and encryption of confidential information using short keys. Due to its nature it supports short messages and fast transactions. This is necessary in capturing transport data since it changes rapidly and the devices involved in the communications process are highly dynamic.

➤ It has no mechanism for IP address hand off between RSUs and therefore all devices change IP addresses when OBU moves from one RSU to another.MAC addresses are randomly generated out of local space. Certificates are provisioned by manufacturers, RSUs and probe vehicles give certificates conforming to existing admin hierarchies-hierarchical certificates.

2.2.1.2. GSM –Global system for mobile communications

- This is an open digital technology for mobile voice and data transmission. It uses Time Division Multiple Access (TDMA) and Frequency Division Multiple Access (FDMA) techniques for access.
- It has a data rate of 64kpbs to 120 Mbps and operates on the 933-960 MHZ uplink and 890-915 MHZ downlink. It uses Gaussian Minimum Shift Keying (GMSK) modulation method.
- This method has broadcast capability through its short text messages where it can be linked with twitter and email accounts to give traffic alerts.
- Mobile phones are now widely available hence they form a very good medium to collect and disseminate traffic information. They can also be used to provide a connection to the internet which is a key source of sending and receiving information from a central facility through a transport information web portal.
- General Motors have connected cell phones to the dashboard of their cars capable of make an automated call in cases of a crash ,this is called e-call hence a lot of information can be relayed to the central transport facility through use of phones.

2.2.1.3. USE OF TWITTER FOR TRAFFIC UPDATE.

- Twitter is a social networking site that is popular and involves users to follow a person or event of their choice. This allows groups of users to share information from a common person or topic. This is now being used to give topic information and news including updates on traffic information.
- Large scale events visualization via twitter was introduced by Dorke et al (2010) whereby he used key words in tweets to group them and to extract information which can be analyzed to give meaning in steps as shown below.
- Tweets are captured to form data via twitter stream and search API, the data is then processed using the following methods:
 - a. Burst detection
 - b. Text classification
 - c. Online clustering
 - d. Text classification

e. Geo tagging. This involves plotting the keywords on a Google map based on their occurrence in the globe using a Google map marker. This involves integrating twitter with GIS for better analysis and interpretation.

➤ Twitter processes the data through text analysis of the twitter data which involves gathering images and retweets, removing noisy information and stop words, stemming words with similar meaning and then associating extracted words to the real post. Then the visual backchannel is used to display a clear visual picture of the current happenings and current topic. In this case it can be used to display traffic information from tweets that contain information on traffic.

2.2.1.4. GOOGLE TRAFFIC INFORMATION

➤ Google has teamed up with the highway authority and traffic data centres to provide real time traffic information.

➤ This is done using Google maps which are gotten by use of satellite imagery which gives high resolution images of places all over the world. The maps have been integrated to smart phones using android technology which uses triangulation methods to give the exact locations of the smart phones and then the android Google maps navigation system is used to give traffic reports and route guidance.

➤ The Google maps API enables them to be utilized by other websites and systems. They can therefore be integrated to a separate system and be utilized to provide GIS information.

➤ The top right corner of a Google map gives the information. This Google traffic information is also available in android phones. The level and speed of traffic is shown by various colour codes.

➤ Endarpo et al (2011) used local natural language processing to process information from a twitter account and use it to update the traffic condition in Jakarta.

➤ Google maps are available for literary all places in the world since it utilizes satellite imagery, this therefore makes it to be most efficient to use in relating traffic information to locations hence better analysis and utilization of traffic data since analysis can be categorized to regions or road sections.

2.2.1.5. GPS GLOBAL POSITIONING SYSTEM

This is a satellite based navigation system that provides information on location, time, weather and travel speeds and distances from origin to destination. The system is composed of 31 satellites orbiting at 20200 kms above the Earth, they are spaced such that at any one time a user can be able to view at least six of them.

The satellites continuously broadcast position and time information to users through handheld or portable receiver devices.

The receiver device receives data from the closest satellites and triangulates the data to find its location, speed, elevation and time.

The GPS technology has now been included in smart phones through the android Operating system and in various vehicle On Board Units hence they can be used for navigation and to support automatic vehicle location systems. This also forms an important component of the probe vehicle system.

This forms a critical part of the GIS system since it will help in tagging of traffic information to specific places. It is therefore the preferred technology for use in probe vehicles and in vehicle OBUs.

2.2.2. SAMPLE TRAFFIC MANAGEMENT SYSTEMS

2.2.2.1. Japan Vehicle Information and Communication System (VICS).

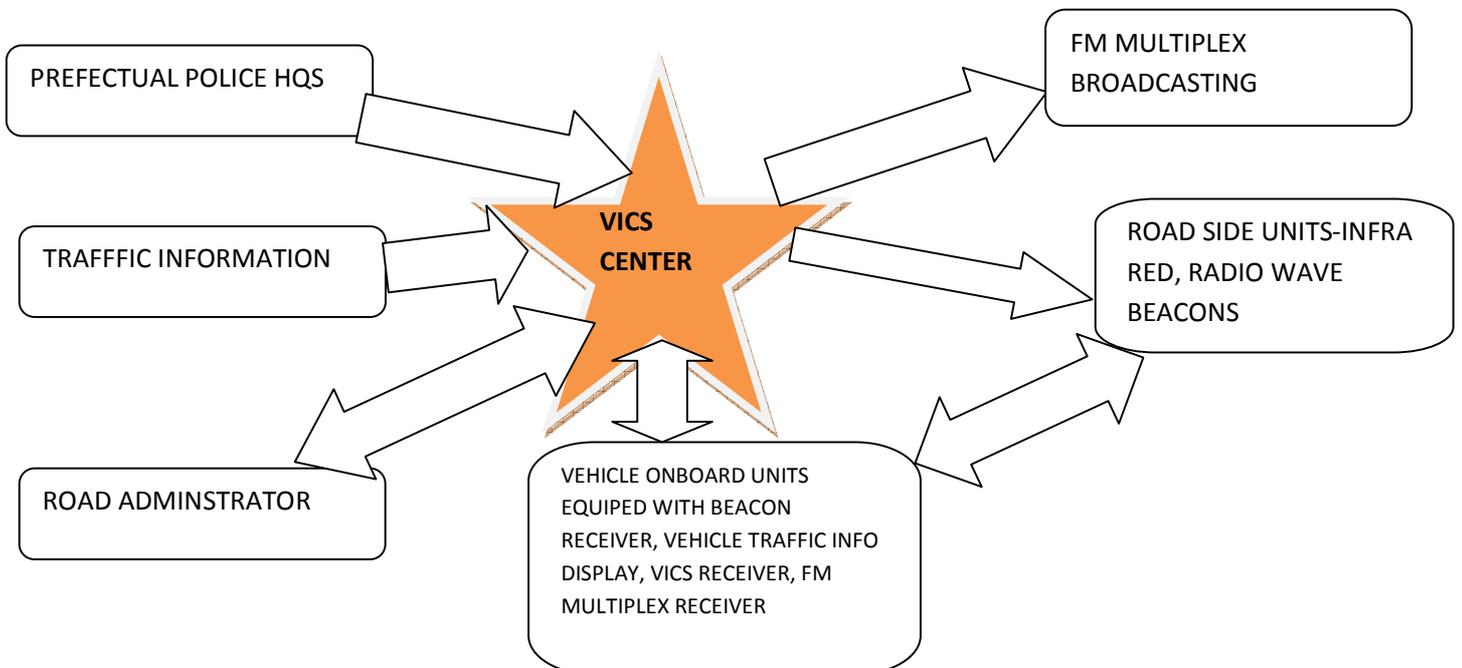


Figure 2.4. Japan's VICS system

➤ It was the first traffic system in the world rolled out in 1996. This is a technology used in Japan for delivering traffic and travel information to road users. It is an up-to-the-minute, in-vehicle digital data communication system providing traffic information to drivers through their on-board vehicle navigation system. Infra red beacons provide VICS information up to about 30km in front and 1 km backwards when a vehicle passes within 3.5 m of the beacon, they are therefore used for arterial roadways whereas a radio wave beacon provides up to 200 km in front when a vehicle passes within 70 m of the beacon, this therefore makes them suitable for use in highways. It also uses the VICS enabled vehicles as probe vehicles to send information to the VICS centre for traffic monitoring, analysis and dissemination. The VICS on board units have the ability to process the information received and help the driver in optimal route selection to destination.

➤ VICS uses Infrared and microwaves for transmission using 5.8GHz DSRC technology. The information can also be available to FM broadcast channels. It displays data as simple text data, simple diagrams or Data superimposed on the map displayed on navigation unit.

2.2.2.2. JAPAN'S SMART WAY. This system evolved from the VICS system. It is designed to offer the following services:

- Traffic information and driving assistance, it uses map and data stores on the vehicle navigation units to warn drivers of black spots and weather warning using camera images to give the weather situation ahead.
- Internet connection to give comprehensive real time traffic information on the control center's website.
- Cashless payment services e.g. at petrol stations and toll stations
- It will also offer traffic information in audio and visual format, the information will also be location and contextual specific through the use of vehicle location systems which utilize the GPS technology.
- This system will also utilize the DSRC enabled roadside units to enable two way communications between vehicles and the system.

2.2.2.3. SOUTH KOREA. It has the express traffic management system (ETMS) which collects information in three ways i.e.

- Vehicle detection system (VDS) which are installed inductive loop detectors at intervals of 1 Km whereby they give traffic flow speed, volume and density.

- Closed circuit cameras placed at 2 to 3 kms apart to give live pictures of traffic situations in those areas.
- Probe vehicles which can give traffic flow information.

The data obtained is then transmitted to South Korea's National Transport Information Center (NTIC) via a very high speed optical telecommunication network which also supports other systems like electronic toll collection and electronic fare payment system. The NTIC aggregates the data from 79 different authorities.

Collected and processed information is disseminated to road users through the following methods:

- Vehicle message signals
- The internet through the NTIC website which gives graphical representations of traffic flow
- Through radio broadcast channels
- LED or LCD screens in public transport terminals
 - 300 The bus stops communicate directly with the central traffic Operations management in Seoul via wireless communication using the DSRC communication and they provide information about bus arrival times, locations and statistics. This information is displayed on LED or LCD screens placed at the bus terminals.
 - The country also has T money for fare payment using the smart card system.

2.2.2.4. KENYA. Kenya intends to use traditional traffic control measures like having unidirectional CBD streets, dedicated bus routes, removal of CBD parking and encouraging high occupancy vehicles, the NMR program making no mention of using ICT to manage traffic.

- There is a project that has been mooted under the IBM project to make Nairobi a smart city where by various ICTs will be utilized to monitor essential services like environment, power and water supply and also in the monitoring of transport sector this will therefore involve embracing the use of ITS systems for traffic management.
- There is also a plan to install CCTV cameras to monitor and control crime and smart traffic lights which can adjust the light colour timings in light of the prevailing traffic situations within the Nairobi CBD to control traffic. Currently individual road users and the Kenya Red cross volunteers tweet on road incidents especially when there is an accident.

- There is some effort being made by radio stations to report on the traffic situation especially during rush hours. This involves use of volunteers who call in and notify the presenter on the current road situation for him or her to relay the same to the public. This is however subjective and it depends on the way the reporter perceives the traffic it also depends on his communication skills. In case the reporter is unavailable or lacks airtime the situation will remain unknown.
- Kenyan branch of Red Cross has established a twitter link which also uses volunteers to report on traffic incidents more especially accidents on the roads

2.3. TECHNOLOGICAL ADVANCES

- Various organizations and countries have put a lot of effort to develop various ITS systems for better performance and to provide novel ways of managing the transport network. Various new systems for data collection, analysis and dissemination have been developed as follows:

2.3.1. TDC systems

- This is a suite of software that is designed to download and verify the traffic data that has been collected by the data monitoring systems. It has the following packages:
- A database management software –H.COMM 100 Database management software
- It can collect traffic flow information for the HI TRAC counter classifiers for data analysis and reporting.
- it can generate traffic reports and present the output in a visual format..

H.COMM RTV software –it provides the user with a way to view ,record ,print weigh in motion data along with vehicle number plate in real time.

2.3.2. DATA PROCESSING SOFTWARE.

a. Flexiroad.

- This is a traffic analysis system which uses a camera connected to a server with various applications for traffic analysis.
- It is based on video motion tracking, it can count and classify vehicles

- It can measure average vehicle speeds and automatically detect road accidents and traffic jams.
- It has an open structure hence can easily be integrated to existing network.

b. TIC software

- This is a commercial software which was first built in the US in 1997 by GEWI company for software development.
- It has the following characteristics:
 - i. It has a configurable platform for customized solutions
 - ii. It has high availability with load balancing and failover
 - iii. It can create and update data using intuitive interfaces like auto complete technology and this can be done locally or via a web or mobile.
 - iv. Can receive data from various sources through FTP or HTTP and in various formats e.g. XML. The data is then checked, referenced, aggregated and harmonized before being stored.
 - v. It can create traffic flows from GPS and sensor information and create events from the flows.
 - vi. It can send out data to different output devices in various formats.
 - vii. It generate reports and manages a database for storing the traffic information

c. Transsuite software package

- This offers a suite of software with a combination of features and functionality for integrated traffic system management as follows:
 - i. Traffic control system
 - ii. Travel information system
 - iii. Event management system
 - iv. Freeway monitoring system
 - v. Map application which displays traffic status, devices and incidents.

- It can accommodate up to 2000 system detectors and road controllers simultaneously
- It can generate and store reports
- It allows for multiple user interaction with the system.

2.3.3. Intelligent speed adaptation system

- This is a system that has been developed to constantly monitor the vehicle speed against the local speed limits, when it is exceeded then an action is initiated to either warn the driver or to control the vehicle driving systems.
- This system uses GIS information stored on the vehicle OBU or information obtained through optical devices or road side units.

2.3.4. Dynamic Traffic Light Sequence

- Intelligent RFID traffic control has been developed for dynamic traffic light sequence whereby RFID technology is used along with some algorithms to determine and give an efficient time management scheme for the traffic lights.
- This is based on the number of vehicles that are detected in a column using the RFID technology. Therefore the dynamic lights have the ability to intelligently adjust itself in light to changing traffic conditions at a junction.

2.4. **CRITIQUE OF THE LITERATURE.** After careful analysis of the literature the following issues are evident:

2.4.1. **Lack of systems integration.** Various traffic systems have been developed by various organization with specific objectives and targets in mind for example vehicle tracking systems concentrate on using GIS information and GPS technology for automatic vehicle location normally for fleet management and crime prevention purposes. Road traffic managers use smart CCTV to manage traffic and ease congestion on the roads. This therefore implies that the systems operate independently and hence lose out the benefit of improved data utilization through a centralized data pool.

2.4.2. **Reduced user –system interaction.** Most of the systems in place are either proprietary or government controlled with limited involvement of the general public in terms of data input or utilization hence reliability is reduced through reduced input of data.

2.4.3. **Underutilized capacity.** ITS potential remains unutilized since some functionality are underutilized hence denying users the efficiency they should derive from the system for example information dissemination has not been extended to the homes by use of dedicated FM radio and TV channels.

2.4.4. **Variation in hardware characteristics.** The various technologies that are utilized for Intelligent Transport Systems have various advantages and disadvantages and they also have varying levels of accuracy. It is therefore important to establish the most suitable ICT to use for a particular case depending on the requirements e.g. level of accuracy required, weather endurance and costs.

2.4.5. **Lack of quality control and standardization** Use of ICT for transport management is a relatively new field where researchers have expressed a lot of interest. Therefore a lot of algorithms, software and hardware for traffic management are being produced .It is however important to note that there is little effort that has been made to standardize the ICTs and also to test the systems for quality and performance. Some effort by IEEE has been made by coming up with a protocol for ITS which is IEEE 802.11p.Users must therefore be cautious when deploying the ITS systems by doing a careful analysis and tests to establish the best system to use.

CHAPTER THREE

METHODOLOGY.

3.1. Research methodology refers to the ways in which research studies are designed and the procedures by which data is analyzed (Prof Williams, 2012). Research can be done using both qualitative and quantitative methods.

3.2. **Quantitative methods.** These methods deal with numbers or use of statistical methods in data collection and analysis. They are deductive in nature and leads to inductive generalizations. Examples of this `method includes:

3.2.1. SURVEY METHOD.

- A survey is a systematic method of collecting data from a population of interest. It tends to be quantitative in nature and aims to collect information from a sample of the population such that the results are representative of the population within a certain degree of error. Centre for Health Promotion, University of Toronto (1999).
- Kraemer (1991) identified three distinguishing characteristics of survey research as follows:
 - i. Survey research is used to quantitatively describe specific aspects of a given population
 - ii. The data required for survey research is subjective.
 - iii. Survey research uses a population sample from which the findings can later be generalized back to the population.

STRENGTHS

- McIntyre (1999) noted that surveys are capable of obtaining information from large samples of the population.
- Bell (1996) observed that they are also well suited to gathering demographic data that describe the composition of the sample.
- McIntyre (1999) also observed that surveys are inclusive in the types and number of variables that can be studied and require minimal investment to develop and administer.

- McIntyre (1999) also notes that surveys are relatively easy for making generalizations and are especially useful when eliciting information about attitudes that are otherwise difficult to measure using observational techniques.
- With careful design, surveys are also good means of looking at a far greater number of variables than is the case with the experimental approaches.
- Surveys can also provide a reasonably accurate description of real world situations from a variety of viewpoints.
- Surveys enable researchers to complete structured questions with many stakeholders within a relatively short time frame.
- Surveys can be completed by telephone, mail, fax, or in-person saving time enabling high volume of information to be collected within a short period of time.

WEAKNESSES

- Pinsonneault and Kraemer (1993) noted that surveys are generally unsuitable where an understanding of the historical context of phenomena is required.
- Bell (1996) observed that biases may occur, either in the lack of response from intended participants or in the nature and accuracy of the responses that are received.
- Respondents may intentionally misreport to confound the survey results or to hide inappropriate behavior.
- Respondents may have difficulty assessing their own behavior or have poor recall of the circumstances surrounding their behavior.
- Little insight is usually gained regarding the causes or the processes behind the phenomena under study.
- Likelihood of bias on the part of the respondents (especially those responding to questionnaires, since they will be self-selecting), in the researcher, and in the time that the research is undertaken
- More difficult to collect a comprehensive understanding of respondents' perspective (in-depth information) compared to in-depth interviews or focus groups.
- Requires some statistical knowledge, sampling and other specialized skills to process and interpret results.

3.2.2. EXPERIMENTAL METHOD.

- An experiment is defined as an operation or procedure carried out under controlled conditions to discover an unknown effect or law, to test or establish a hypothesis, or to illustrate a known law.
- Experiments rely on precise and detailed observation of outcomes and changes that occur following the introduction or exclusion of potentially relevant factors. They also involve close attention to the measurement of what is observed. Prof Williams (2012).

- Simulation and modelling are also considered as experimental methods which are mostly applicable to ICT research.

STRENGTHS

- Creation of new ideas and insights
- Researcher has control over variables
- Contributes to cumulative knowledge

WEAKNESSES

- Subject to human error
- Sample may not be representative.
- Restriction to a single event limits generalization
- Difficulty in devising a simulation that is similar to a real life situation.

3.3 **Qualitative methods.** These are the ones which are more exploratory, inductive and descriptive in nature. An example of this method is:

3.3.1. CASE STUDY.

- Yin (1994) defines case study in terms of the research process as
 - "An empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident."
- a case study can accommodate a variety of:
 - research designs,
 - data collection techniques,
 - Epistemological orientations and disciplinary perspectives, each with its own standards of scholarship.
- It is an inductive approach to research where the researcher is the primary instrument for data collection which uses various methods like interviews, questionnaires and observation.
- The researcher also spends considerable time in the natural setting of the study often in contact with the participants.
- The end product of the research is often narrative and descriptive.

STRENGTHS

- Gives insight to the underlying causes of phenomenon
- Can be applied in a wide range of disciplines since it can accommodate different epistemologies
- It offers a flexible yet integrated way to analyze phenomena in a natural state.

WEAKNESSES

- Difficulty in generalizing findings since its tied to a single phenomenon.
- Lack of control of individual variable hence difficulty to distinguish cause and effect.

1.3.1 Characteristics of quantitative and qualitative research

	Quantitative		Qualitative
The role of theory in research	Deductive	← →	Inductive
Epistemological orientation	Naturalist, positivist	← →	Interpretive
Ontological orientation	Realist	← →	Idealist, constructivist
Characteristics of research approaches	Objective	← →	Subjective
	Impersonal	← →	Personal
	Reductionist	← →	Holistic
	Generalisation	← →	Uniqueness
Types of data	Quantifiers	← →	Describers
	Numbers	← →	Words

Source: developed from Bryman (2008) and Onwuegbuzie and Leech (2005)

Table 3.1. Comparison of qualitative and quantitative methods by Bryman et al (2008)

3.3.2. SIMULATION AND MODELLING METHOD

- Simulation provides an efficient way to monitor and study traffic conditions under a variety of conditions. This is helpful in studying complicated road models and also for research purposes because it is cheaper than practical studies.
- Depending on the system state being considered a simulation can be classified in either of the two ways namely:
 - a. Continuous simulation. This is where the elements of a system change state continuously over time in response to changing stimuli (Dr Spivak, 2003).
 - b. Discrete simulation .This is a simulation model that assumes that the system states change abruptly at points in time.

- Simulation can be done at three levels depending on the level of detail considered namely:
 - a. **Microscopic simulation**-This simulation describes both the system entities and their interaction at a high level of detail for example in a road traffic simulation, it tracks the movement of the individual vehicle on a second or subsecond basis.

It relies on random numbers to generate vehicles, select routing decisions and determine vehicle behavior

It produces two types of results namely;

- i. Animated displays
- ii. Numerical text files

Disadvantages

-they are computationally intensive

-require development of complex algorithms to implement.

- b. **Macroscopic simulation**. This one describes system entities and their interaction at a low level of detail.It uses aggregates or sectionalized information. For example cars in a section can be grouped as a cell.
- c. **Mesosopic simulation**. This simulation represents entities at a high level of detail but describes their activities and interactions at a much lower level of detail.

3.3.3. SAMPLE TRAFFIC SIMULATORS

a. **AURORORA ROAD NETWORK SIMULATOR.** This is a graphical application with interactive user interface that runs traffic simulations on road networks.

Traffic flow and density are computed using the macroscopic Cell Transmission Model. It also computes such traffic characteristics as speed, delay and productivity loss and generates flow, density and speed contour plots making it convenient to compare with the real traffic data.

b. **TransModeler**

TransModeler is a powerful and versatile traffic simulation package which can simulate all kinds of road networks, from freeways to downtown areas, and can analyze wide area multimodal networks in great detail and with high fidelity.

You can model and visualize the behavior of complex traffic systems in a 2-dimensional or 3-dimensional GIS environment to illustrate and evaluate traffic flow dynamics, traffic signal and ITS operations, and overall network performance.

With TransModeler you can be able to do the following:

- Manage a variety of input files for multiple scenarios
- Share project databases, traffic signal timing plans, and other input data between multiple projects
- Export subareas of larger networks to simulate traffic operations on a more localized scale
- Compare output results from multiple simulation runs
- Generate nicely formatted reports, maps, and charts for inclusion in reports and presentation slides

Advantages

-it is easy to use.

-can be used for future traffic planning scenarios since it has a travel demand forecasting software to provide an integrated capability to perform operational analysis of transportation projects and plans.

- TransModeler mapping, simulation, and animation tools allow you to present study findings to decision-makers in a clear manner.

-TransModeler models the dynamic route choices of drivers based upon historical or simulated time dependent travel times, and also models trips based on origin-destination trip tables or turning movement volumes at intersections.

- It simulates public transportation as well as car and truck traffic, and handles a wide variety of ITS features such as electronic toll collection, route guidance, and traffic detection and surveillance. Traffic simulation results can also be fed back for use in travel demand forecasting.

c. FREESIM SIMULATOR

This is a customizable macroscopic and microscopic free flow traffic simulator which allows for multiple free way systems to be easily represented and loaded into a simulator.

Vehicles in Freesim can communicate with highway monitoring systems.

d. SUMO (Simulation of Urban Mobility).

It is an open source traffic simulator which can give microscopic and multi modal simulation.

It has the following features

- This is a simulation that is implemented in C++.
- Collision free vehicle movement
- Can simulate different vehicle types
- Can handle large road networks with multiple lanes with provisions for lane changing
- It has a route and network generator but can also use those generated by other applications.

e. TRAFFS

This is a road traffic simulator that does micro simulation

It has a network editor that permits for creation of different simulation scenarios by the user.

It is a discrete event, object oriented simulator.

It however requires fast computers for it to show reasonable animated speeds.

f. SINDRA INTERSECTION

This is a suite of simulation software package use for intersection capacity, level of service and performance analysis by traffic professionals.

g. SYNCHRO STUDIO.

This is a software suite for modeling, optimizing and visualizing traffic networks.

It is also used for analysis of capacity and timing optimization.

It helps to check and fine tune traffic signal operations.

COMPARISON OF ROAD TRAFFIC SIMULATORS

S/NO	DESCRIPTION	CHARACTERISTICS	REMARKS
1	AURORA	<ul style="list-style-type: none"> -It has an interactive user interface. -Traffic flow and density are computed using the macroscopic model. 	
2	TRANSMODELLER	<ul style="list-style-type: none"> - can model complex traffic systems in a 2-dimensional or 3-dimensional GIS environment. -Share project databases, traffic signal timing plans, and other input data between multiple projects -Export subareas of larger networks. -Compare output results from multiple simulation runs -Generate reports, maps, and charts. 	<ul style="list-style-type: none"> -- powerful and versatile traffic simulation package which can simulate all kinds of road networks, from freeways to downtown areas, -has high levels of fidelity.
3	FREESIM	<ul style="list-style-type: none"> -It is a customizable macroscopic and microscopic free flow traffic simulator. - allows for multiple free way systems simulation. -Vehicles in Freesim can communicate with highway monitoring systems. 	
4	SUMO	<ul style="list-style-type: none"> -It does microscopic and multi modal simulation. -It is implemented in C++. -Collision free vehicle movement -Can simulate different vehicle types -Can handle large road networks with multiple lanes with provisions for lane changing 	<ul style="list-style-type: none"> -It is a well established simulation software that is widely used

		-It has a route and network generator but can also use those generated by other applications.	
5	TRAFFS	-It does micro simulation - has a network editor that permits for creation of different simulation scenarios by the user. -It is a discrete event, object oriented simulator.	- It however requires fast computers for it to show reasonable animated speeds.
6	SINDRA INTERSECTION	-it is used for intersection capacity, level of service and performance analysis.	
7	SYNCHRO STUDIO.	- used for analysis of capacity and timing optimization. -It helps to check and fine tune traffic signal operations.	
8	AIMSUN	-Its proprietary software for macroscopic, mesoscopic and microscopic simulation -can be customized using python or C++ -It can create vehicle actuated signals -It can import GIS data -production of output as images, videos, graphs or tables	

Table 3.2. Comparison of road traffic simulators.

PROPOSED METHODOLOGY

3.4. Various methods will be used both for data collection and for testing of the system model as follows:

- a. Survey method will be used to gather traffic statistics on sample Kenyan roads so as to establish traffic trends for analysis, this will involve taking sample traffic volumes, density and average vehicle speeds at particular times and locations of the roads, this data will be essential during validation of results obtained through simulation, they will also help in setting of the parameters and input to be used during simulation.
- b. Laboratory experiments will be used to test the various parts of the system. This will involve physical testing of the system hardware to establish its suitability in the following areas:
 - Ability of the transmission medium to cope with the bandwidth of data generated
 - Endurance of the hardware to the physical conditions of sun, rain and dust.
 - Routing capabilities of the routers
 - Capacity of the database systems against the system requirements

Advantages

- Results are highly accurate and are a true representation of what to expect in reality, therefore validation is easily achieved

Disadvantages

- Likely to be expensive
 - Sophisticated methods may be needed for testing.
- c. Modeling and simulation will be used to test the systems model that will be developed. This will be done as follows:
 - A model of a specific transport system will be designed with the necessary components like interchanges, roundabouts, arterial roads and the various ITS components that will be used to monitor and manage the system like the sensors, transmitters, communication systems and processors of the resultant traffic data.

- Three steps will be employed during the simulation process namely
 - i. Calibration
 - ii. Verification
 - iii. Validation

Calibration-this involves adjusting of the simulation parameters necessary to operate the model and simulate the transport process in the selected area. The parameters include the following:

- Look ahead distance
- Distance between cars
- Acceleration rate from a stop or intersection
- Entry rate from an arterial road
- Start up lost time
- Braking distance and rate when approaching a stationary car.
- Allowed highway speed limits

Verification. This is comparing of the output data with what is expected considering the input given. This is to establish the closeness or error margin. For example if a traffic density and volume is fed into the model and the parameters set then the output should be reasonable within the input figures.

Validation. This involves comparing simulation results with what is expected in reality, the traffic density, volume and vehicle speeds produced by the model will be compared with actual realistic figures from the areas covered. The following tools can be used for validation:

- R2 statistic-it measures the fraction of variability that is accounted for in the model.
- Graphical residual analysis

Likely sources of error include:

- Input error-through inputting the wrong figures
- Parameter error-due to improper or inappropriate choice and use of parameters
- Model error-due to use of wrong methodology in the model.

Advantages of simulation

- Saves on costs of research validation
- Various scenarios can be tested by changing parameters which can be elusive in the real world

Disadvantages

- May not capture all the factors that affect traffic in the roads

CHAPTER FOUR

CONCEPTUAL MODEL AND FIELD STUDIES

4.1 The system will involve communication to and from the vehicles and other transport stakeholders, the following systems will be integrated:

- a. Real time traffic management system to include traffic broadcasts and adaptive traffic lights and speed limit signs system.
- b. Vehicle tracking and location information system
- c. Transport emergency services like vehicle breakdown, weather warning and accident reporting systems.
- d. Public service vehicle management system to give vehicle locations, estimated arrival times and allow for booking and payments.

System components.

4.2. This system will comprise of three parts namely:

4.2.1. The data collection and input system. It will comprise of all the technologies employed to gather traffic information as follows:

- a. Probe vehicles-this are selected vehicles that are fitted with communications devices such that they can be able to communicate with road side units so as to give their travel speeds which are relayed to the central processing unit.

Types of probe vehicle data collection:

- Sign based automatic vehicle location-they communicate with transmitters mounted on existing sign posts. Roadside transceivers communicate with probe vehicle electronic tags using either cell phone tracking, GPS or radio communication.
- The selection of vehicles for use as probe vehicle will be based on the vehicle frequency of passing a given highway and driving routine, especially passenger service vehicles that are likely to pass a given area for regular time intervals. The sample size is also determined by expected traffic density. Srinivasan and Jovanis algorithms are some of the algorithms that have been developed to estimate the number of probe vehicles needed.

- b. Inductive loop detectors
- c. Closed circuit cameras
- d. Internet/mobile phone connections from road users
- e. Vehicle telematic devices

4.2.2. Data processing and analysis system. It will comprise of the central transport operations centre where various applications will be used to analyze received traffic information and translate it to meaningful information. It comprises of the following:

- The system control information,
- A traffic database system
- The system administrator
- Information output interface.

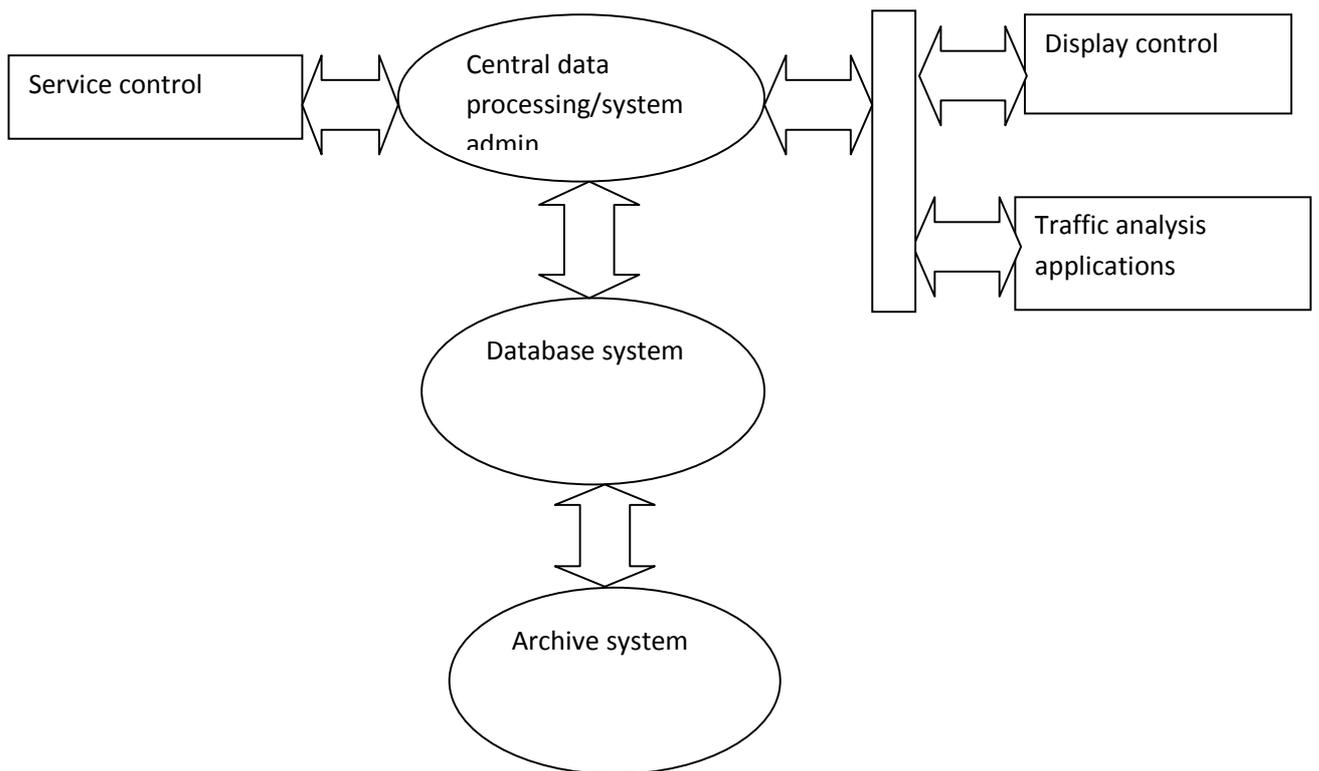


Figure 4.1. Components of the central operations and analysis system

This system will carry out the following functions:

- (1) Vehicle density and flow analysis and aggregation to give the actual traffic information on a particular road in real time and also give signal information that will control the adaptive traffic lights and variable message signals.
- (2) Stalled vehicle, accidents and adverse weather information will be received analyzed and channeled to the relevant recipient.
- (3) A database management system will also be used to offer customized information and respond to individual queries regarding any aspect of the transport system. An extension for an archive system will also be included to store traffic information over a period of time for use in analysis to inform policy or for forensic purposes and any other investigations and litigation processes.

4.2.2.1. DATABASE SYSTEM

This is the backbone of the system as it receives data from the collection systems, stores it and ensures that the information can be retrieved and sent to output devices when required. Therefore the database should be robust for fast and easy storage, retrieval and analysis.

The capacity should also be big enough since all the data for the system will be centrally stored. To guard against disaster there will be need for back up data to be stored in an offsite location with a backup server.

The database will be stored in a modular format with each data stored in an individual table in the database referenced by a unique date/time identification key with the location of the data collection point.

The database has three types of programs namely:

- Database administration programs which provide admin functionality like crash protection, disk management and internal data storage and retrieval. These programs are opaque and cannot be developed when implementing the system.
- Data aggregation programs which prepare the received data for analysis by aggregating it to reasonable time intervals and space in order to enable meaningful analysis.
- Data analysis programs which are used to analyze the data for example delay calculation module, congestion analysis module, emergency warning module and system bottleneck analysis.

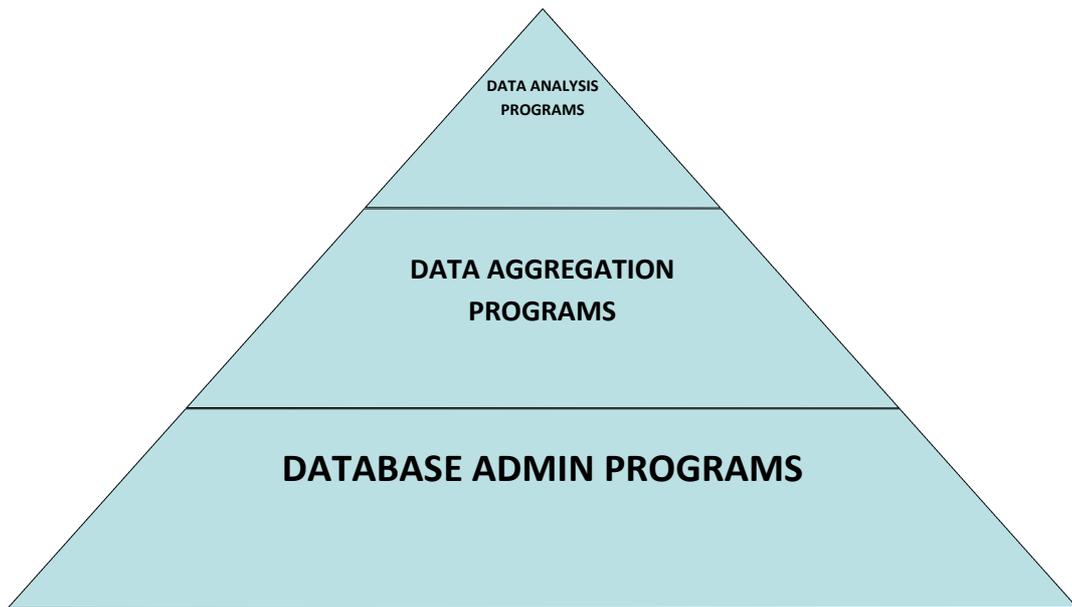


Figure 4.2. Database program stack

The following data transfer protocols will be used:

- Hyper Text Transfer Protocol (HTTP)
- Extensible Mark up Language (XML)
- Structured Query Language (SQL)
- File Transfer Protocol (FTP)
- Simple Object Access Protocol (SOAP)

The database system will have the following characteristics:

- It has a relational database for storing all the data in the system. The database management software used should have SQL compatibility.
- GIS functionality for referencing the data to a location on a map, this will also leverage the system to utilize and display digital mapping services like Google maps, openstreetmap or bingmap. The database can have its own local set of map data also for the area covered by the system.
- Temporal and spatial aggregation capabilities .This is because data from the field normally has very fine granularity of up to milliseconds, it is therefore necessary to aggregate it to about five to 10 minutes for meaningful analysis to be done. Spatial analysis will also assist in the sectionalized or entire road analysis
- Should have a web interface to allow for access to online users who will use secure log in sessions with user accounts and passwords to access restricted data. Unrestricted data can be channeled to the transport operations website for all users logged on the internet to access.

DATA QUALITY CONTROL

4.2.3. Programs will be installed in the system to check the data for errors in real time. They will check for inconsistencies, identify and exclude erroneous data. It will also fill missing data to allow for proper analysis. This is done through the following methods:

- Univariate and multivariate range checks
- Spatial and temporal consistency checks
- Detailed diagnostics

4.2.5. The output/ information dissemination system. It will comprise of all the technologies that will be employed to display the transport information and also to actuate any necessary automated traffic control system as follows:

- Vehicle on board units which will display real time traffic information and weather warning information, they will also show best routes to destination based on traffic aggregation applications for best route selection like tomtom devices.
- LED or LCD screens placed at bus terminus and other strategic places will give information about public transport systems like vehicle locations, expected arrival times, delays and vehicle capacities.
- Variable message signs will give information on weather and other road warning information based on received data. It can also be used to give variable speed limits on roads based on the prevailing traffic information.
- The transport operations centre web portal where various transport information both in text and in graphics will be availed and can be integrated with the mobile phones short message system through the short code system to provide relevant and maybe subscribed transport information, links to twitter and facebook can also be used for internet traffic information provision.
- Use of dedicated FM radio and TV broadcasts channels which will receive information from the operations centre and relay it to the channels for example information on traffic situation ,weather and accident warning and notification information and general road usage tips in real time. The TV channel can provide real time pictures on sections of the roads for transport users to make own decisions, they will also be integrated with the roadside and bus terminals screens to display traffic information after some time intervals.

CONCEPTUAL MODEL

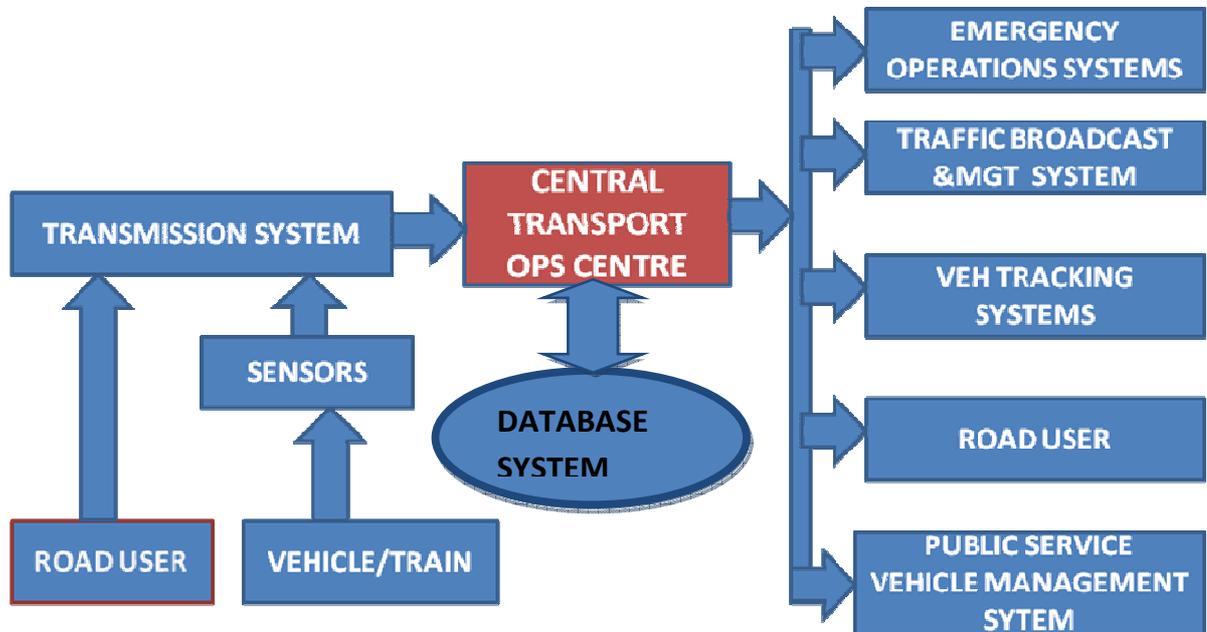


Figure 4.3. The system's Conceptual model

4.3. Data types in the system

4.3.1. Input systems data.

- Information obtained from the vehicle includes:
 - a. Vehicle registration details gotten from an RFID tag in the vehicle as it passes a roadside sensor.
 - b. Vehicle location and speed gotten from the GPS system installed in the vehicle
 - c. The density and traffic situation can be assessed using inductive loop detectors, aerial surveillance cameras and relayed to a central processing area.
 - d. Weather warning information can be sent to broadcast channel on being received in a detector placed in vehicles, some micro weather detection stations can be installed along the road that transmit information to both the operations centre and to the roadside screens directly.

- e. Accident or stalled vehicles can relay a signal from a terminal installed along the road, the onboard units can also initiate a call for both voice and data in cases of an accident.

4.3.2 Output systems data.

- Information that can be sent to vehicles includes:
 - a. Real time traffic information relayed to screens on vehicle dashboards using dedicated channels.
 - b. Information on stalled vehicles on highways
 - c. Weather warning information
 - d. Passenger booking information for public service vehicles.

4.3.3. Operations centre and analysis information.

- Transport operations centre information includes:
 - a. Real time traffic information gotten through CCTV cameras and transmitters connected to highway vehicle detectors, this information will be processed so as to send signals to adaptive traffic lights and variable highway speed limit signs.
 - b. Information on stalled or accident vehicles on the road which will be relayed through dedicated hotlines to various emergency centres ranging from Red cross, hospitals and vehicle recovery agencies like AA motors.
 - c. Vehicles registration information and location details to be used for billing in cases of traffic offences or in cases of tracking of crime for example carjacking.

4.4. SYSTEM SECURITY.

4.4.1. Security is a key component in the system and much consideration should be put in ensuring that the system is not compromised since it can be catastrophic. It should be noted however that most of the components used in the system have been individually configured to provide some degree of protection to attacks. The transmission system especially the 3G networks for cellular transmission has resilience against jamming attacks and has various authentication measures through the handshake procedure. However there is need for a concerted effort by the whole system components to provide a level of overall security.

4.4.2. The system will be designed so as to achieve the security objectives as follows:

- Confidentiality
- Integrity
- Availability
- Non-repudiation

a. Confidentiality. The system will be designed to ensure that the data held within the system is protected from unauthorized access, this is critical especially for management information. Attackers achieve this breach of security through use of eavesdropping, and traffic analysis. It can be achieved by use of the following measures:

- Use of an intrusion detection system to give early warning of entry of unauthorized entities.
 - Authentication for messages and access to the system for the operators two factor authentication can be used by way of passwords and PIN numbers and Identity cards.
 - Encryption can also be employed to prevent eavesdropping.

a. Integrity. This will involve measures to protect the system from unauthorized modifications or deletion of data more especially management and database information. This breach to security occurs in the form of manipulation, masquerade, insertion of information and replay. It can be prevented through the use of the following measures:

- Use of detection systems for detecting data modification or deletion
- General system hardening can help prevention malware from altering data
- Only authorized applications and operations centre staff can make changes to the system and carry out updates and upgrades to the system, this therefore means that administrator rights are only for the system management.

b. Availability. This involves ensuring that the system is available for use by all the stakeholders when needed. This can be achieved by use of the following measures:

- Prevention of Denial of Service attacks through installation of intrusion detection systems.

- Prevention of jamming of transmission systems through frequency agility within the ITS transmission band.
 - Installation of failover systems and provision for redundancy in data storage.
- c. Non-repudiation. It should be possible to audit all the system information therefore the design should provide for logging of information with time and date stamp and also the ID of the senders.

4.5. FIELD STUDIES

4.5.1. So as to validate the research the proposed methodology was employed to carry out field studies so as to establish the suitability and ability of the system to carry out its function.

4.5.2. The following findings were arrived at in the course of the study:

- Most of the cars in the Kenyan roads lack modern vehicle On board units and therefore lack modern communication and navigation capabilities offered by GPS and satellite communication. This therefore implies that Bluetooth, satellite communication cannot be universally employed,
- There are no electronic data collection roadside units on any Kenyan roads, therefore the most suitable ones will have to be installed. The most viable form of data collection will be inductive loop detectors since it does not require installation of any devices on the vehicles, it will give the traffic volume, density and estimated travel times of any vehicle that passes on that segment of the road.
- There are no Smart CCTVs on the Kenyan roads but plans are underway to install them in the Nairobi CBD.
- There is a reliable fleet of Passenger service vehicles (PSVs) which ply on all the major routes of the city and the country in general, most of them are consistent and available on the road from 0300Hrs to 2300 Hrs daily, this therefore makes them suitable to be used as probe vehicles to collect information on the road situation and also to disseminate information to other vehicles and to road side screens.
- Almost 99% of the motorists own a cell phone that can be connected to the internet. This therefore implies that normal cellular GSM communication can be employed to collect and disseminate information. This can also be used to offer text messaging and a link to social networking sites.

- About 50 % of Kenyans are linked to social networking sites like twitter and face book. This can therefore be used as a way to disseminate information from the transport Operations centre for mass consumption especially on emergency alerts and general traffic situations. Users will also actively interact with the site through blogging and giving of traffic updates, they can also query some specific requests to the Ops centre and get a personalized feedback.
- Kenya has an established telecommunications network for both line and wireless communications. There is network coverage across all major highways by the major service providers, which are Safaricom, Airtel, Yu and Orange. Therefore this network will be utilized for data transmission from the road side units to the central transport operations centre and also from the centre to the information dissemination units.

IMPLEMENTATION TECHNOLOGIES

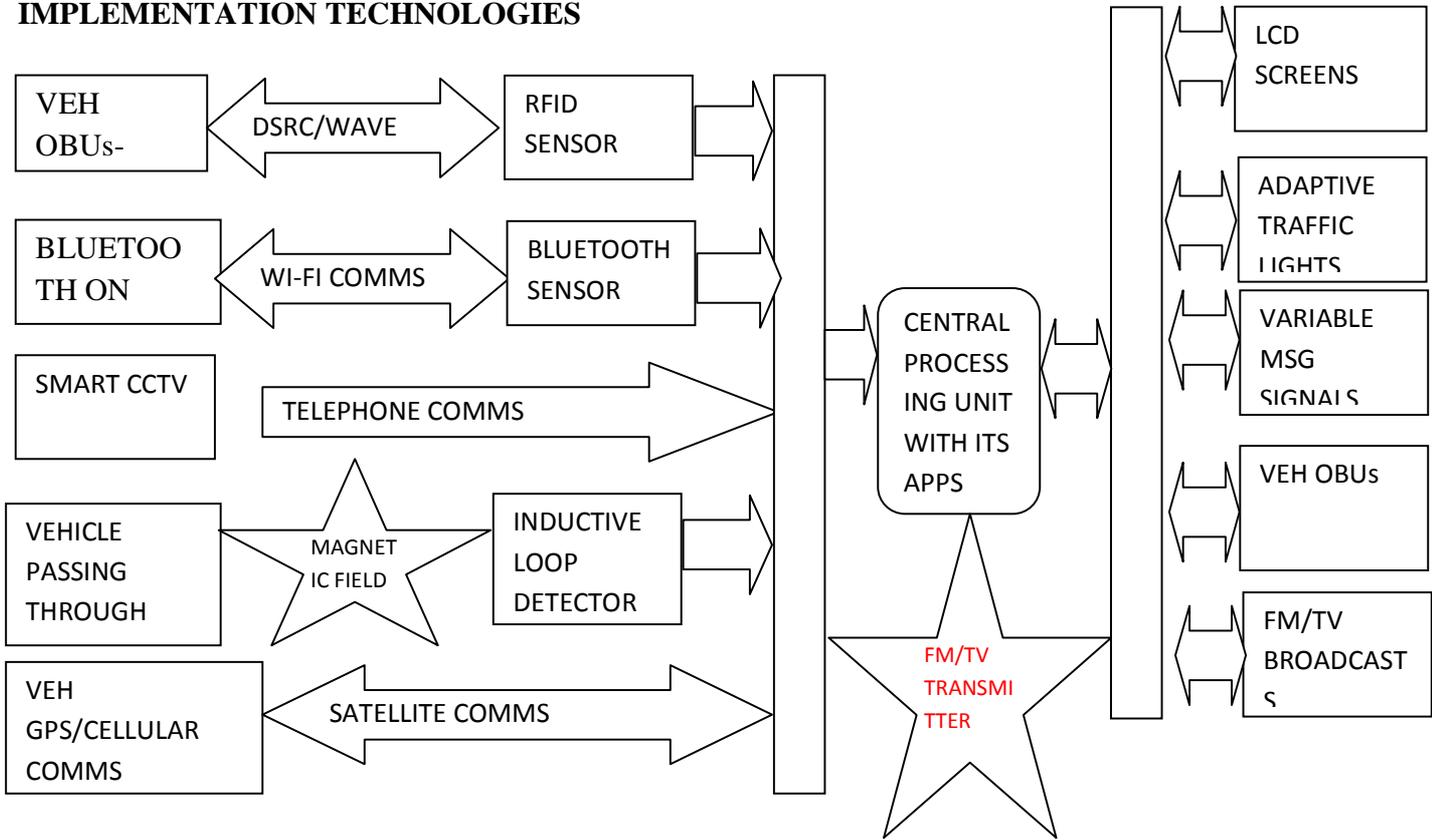


Figure 4.3. Conceptual model of implementing technologies.

CHAPTER FIVE

IMPLEMENTATION MODEL

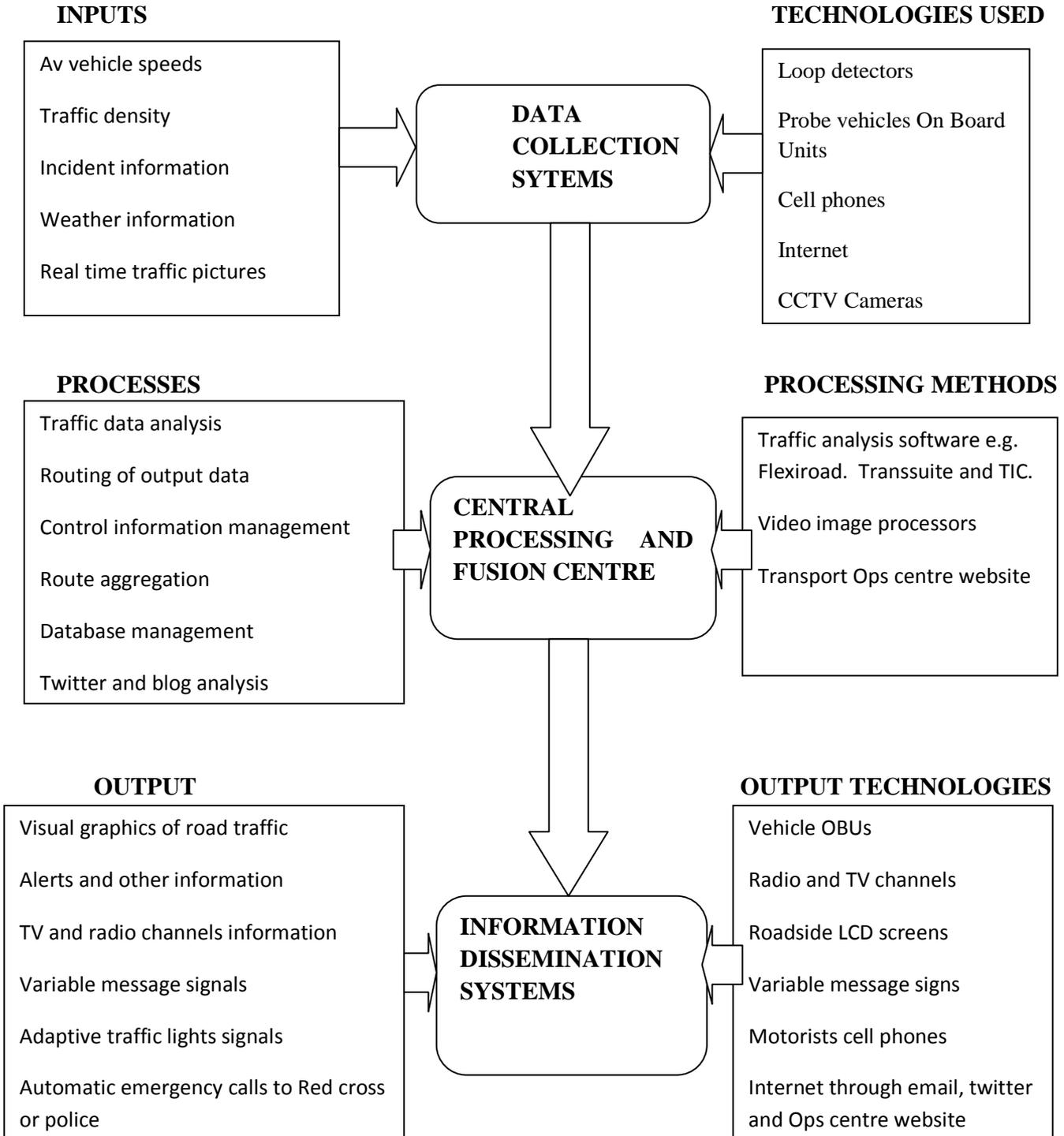


Figure 5.1. Implementation model

5.1. This system can either be implemented in an entire road network or in piecemeal where only some sections of roads are covered by the system, however partial implementation has the benefits of being quick and cheaper to implement as compared to full implementation. In the Kenyan situation the implementation can be done in Nairobi CBD and then rolled out to other parts later. For the purpose of this study only the Thika superhighway has been considered for test implementation.

5.2. The implementation of the system will be based on the following areas.

5.2.1. Data collection systems implementation.

Vehicle detection can be achieved by use of:

- Inductive loop detectors which detect vehicles which pass in the vehicles magnetic loop, they can then count the vehicles in a unit time to give traffic volume and density. They will be placed at a distance of one kilometer apart on the roadsides alongside the traffic lights. The traffic data gathered will be transmitted to a central control facility via normal telephone lines.
- There will be installation of Smart CCTVs which are connected with video processors and automatic number plate recognition systems which will enable them to identify vehicles, give vehicle speeds, volume and density, and the general road situation. They will be placed at a spacing of about five kilometers near major centres to cover all the lanes including service lanes. The processed information will be sent to the central processing unit and to adjacent output units so as to update approaching motorists on the expected traffic situations. Transmission will be done via optic fibre from a node connected to the cameras.
- Probe vehicle systems will also be employed whereby they will be fitted with OBUs to carry out the following functions:
 - i. Collect information on the general road conditions namely weather, stalled vehicles and accidents.
 - ii. Receive traffic information from other probe vehicles ahead and transmit the same to the other vehicle and the transport operations centre.
 - iii. To regularly transmit its own location and speed information to the transport operations centre for traffic analysis.
 - iv. Capture and transmit real time pictures of the traffic situation on the road and send the information to neighbouring vehicles and the transport operations centre.

- The following regular passenger service vehicles can be used as probe vehicle on a voluntary basis:

-Chania travelers Sacco bus to monitor Thika Nairobi part and Zamzam bus to monitor Githurai Nairobi town part.

-A total of 40 buses will be used to give updates at least once every 15 minutes. The updates will be transmitted via normal cellular communication to a central traffic centre and can also allow for communication with other probe vehicles.

5.2.2. **Central fusion and processing and control centre implementation**

- The operations centre will have a database with various servers for the various services, there will be a vehicle registration details server, a traffic information server. The operations computers must be powerful enough and installed with various applications for traffic data analysis and transmission, applications to interface the system with various social networking sites like twitter and face book will also be utilized.

- The central system will have various applications based on the services being offered by the system as follows:

- i. Traffic information application. This will handle all the information meant for broadcast by processing it and routing it to the appropriate recipient channels, it will determine which information is sent to the display units including routine traffic information and even commercial advertisement. It will also determine which information will be sent to control to assist in decision making and actuation of some devices like the adaptive traffic lights system. It will also cross check information for accuracy and discard information in cases where there is inconsistency.
- ii. Traffic emergencies application. This will handle all incident reports on the highway and route all distress signals to the appropriate response agencies like the police, disaster response unit or Red Cross. It will be linked to receive information about stationary vehicles, accidents, adverse weather and other direct hotlines for call in by users to report on emergencies.
- iii. Service control. This will enable exchange of information between the assets in the system for both control information and ordinary traffic information. It will also store and maintain the system state information .It can invoke and control the functioning of the other applications.

- iv. Protocol control. It will select the appropriate data transfer protocols based on the hardware and software that is in use by the system, it therefore processes and converts messages to formats that can be handled in the system for standardization and interoperability since components from different vendors will be utilized in the system.
 - v. Parking management application. This will collect information from parking sensors in the parking spaces and use it determine available spaces for display and relay it to the central database system for users who query the system to get the information.
- A road user in need of some information can query the central system if it is not part of the broadcast information, he should also be able to upload any information to the central operations centre. Therefore the web portal gives the provision for blogging and active real time interaction between the transport system users and the central management centre. There will also be the use of dedicated telephone lines and integration with GSM technology for transmission and reception.

5.2.3. Traffic information dissemination and enforcement section. The output/information dissemination and enforcement section will comprise of all the technologies that will be employed to display the transport information and also to actuate any necessary automated traffic control system as follows:

- Vehicle on board units inside the probe vehicles will display real time traffic information and weather warning information, this information will be passed on to any other vehicles with configured OBUs. They will also show best routes to destination based on traffic aggregation applications for best route selection like tomtom devices using Google maps.
- LED or LCD screens placed at bus terminus and other strategic places will be configured so as to receive and display information about the general traffic situation, incident alerts and other warning information, they will also display real time visual traffic situation on selected sections of the road.
- Variable message signs will give information on weather and other road warning information based on received data for motorists. They will have a link to dedicated emergency communication systems to receive and display emergency warnings and alerts. It can also be used to give variable speed limits on roads as will be directed by the transport operations centre based on the prevailing traffic information.

- The transport operations centre web portal where various transport information both in text and in graphics will be available and can be integrated with the mobile phones short message system through the short code system to provide relevant and maybe subscribed transport information, links to twitter and face book can also be used for internet traffic information provision. The website will also provide visualization of the traffic information and summarized traffic reports for online users.
- Use of dedicated FM radio and TV broadcasts channels which will receive information from the operations centre and relay it to the channels for example information on traffic situation ,weather and accident warning and notification information and general road usage tips in real time. The TV channel can provide real time pictures on sections of the roads for transport users to make own decisions, they will also be integrated with the roadside and bus terminals screens to display traffic information after regular time intervals.

5.3. System control

5.3.1. The bottom up control system also called multi agent control will be used to augment the centralized top down system since it achieves the benefits of scalability, reduced overhead and increased computational capability of the system.

5.3.2. Therefore individual network segments can act as control and neighbouring segments can query each other and provide information that can be used in decision making in a localized manner without relying on the central system.

5.3.3. The segments communicate with each other through request for information on traffic state and request to take certain measures by the neighbouring elements based on obtained information for example reduction of traffic inflow to a certain arterial road due to congestion, this can be achieved by reducing the duration for the green light for the road segment and if it does not work the request is transmitted further upstream.

5.3.4. This bottom up control will involve use of asynchronous middleware to manage the various interfaces of the system since it is more appropriate for real time transmissions.

CHAPTER SIX

DATA ANALYSIS AND CONCLUSION

6.1. Data analysis is crucial for validation of the developed system. This will help to prove if the system is working and its contribution to improving the existing situation. For the transport management system this was carried out by first establishing parameters that will be critical for real life traffic analysis and compare the results with the system simulation results so as to determine the contribution to system improvement.

This is done by using simulation to give a free flow travel speed and time and then compare it with the travel time in excess of the free flow, this will give you the delay which will be used to give an indication of the effectiveness of the Intelligent Transport System.

6.2. Road traffic measurement

6.2.1. Road traffic can be assessed using the following measures:

- a. Quantitative measures like traffic demand, volume, throughput, time headways.
- b. Qualitative measures like speed
- c. Movement measures like travel time, turning movement
- d. Composition classification measures like vehicle identification and types of individual vehicles.

6.2.2. Various parameters have been identified that are critical for the evaluation of a traffic system as follows:

- a. Traffic flow rate. This is the number of vehicles passing a point per unit time. It is given as vehicles per hour (VPH) which equals $\text{speed(KM/HR)} \times \text{density (V/KM)}$. This can also be used to describe the general traffic conditions for example traffic can be described as free flow when there is no delay or congested flow when there is delay. Flow has the limitation of not giving an indication of the speed since it can be congested flow but fast or free flow but slow.

- b. Speed. This shows the rate at which traffic is moving. It gives a qualitative description to flow. The following types of speed measurements are important:
- Spot speed. This is the speed of an individual vehicle as it passes an observation point of traffic stream. It can be measured by use of ultrasound or microwave loop detectors or by use of a speed trap which consists of two loop detectors spaced about 20 feet apart so as to measure the time it takes to pass two consecutive detectors and use this information to calculate the speed.
 - Accuracy in spot speed measurement is affected by:
 - distance between the detectors for speed trap detectors
 - average speed of the traffic
 - detector sampling rate
 - Time mean speed. This is the mean of the spot speeds of vehicles passing an observation point over a period of time.
- c. Density. This is the number of vehicles that occupy a given amount of roadway normally a lane. It helps to quantify congestion or the traffic state. It can be generated and calculated by video processing from CCTV cameras. Speed and flow can also be used to estimate density.
- d. Occupancy. This is the percentage of time a detection zone of a detector is occupied by some vehicle.
- e. Vehicle presence. This is when a detector is able to detect the presence of a vehicle.
- f. Queue length. This is the distance between the head to the tail of a congested section of a road.
- g. Travel time. This is the time it takes a vehicle to travel from the origin to the destination.
- h. Intersection turning movements. This is a measure that shows how often vehicles leave or enter the main highway from or to the arterial roads.
- i. Vehicle classification. This is classifying a vehicle according to types in terms of design, use or size.
- j. Time headway. This is the elapsed time between the passage of an identical observation point by consecutive vehicles in the traffic stream.

- k. Delay measure can be used for traffic analysis. It occurs when the speed is less than that of free flow traffic. It can be at intersection due to stopping, time in queue and approach delay. Delay can be used to measure the effectiveness of an ITS system by measuring the extent to which delay is reduced by introducing the system to a road network that had none previously.

6.3. THIKA SUPERHIGHWAY CASE STUDY

6.3.1. A study was conducted on the Thika superhighway during peak hours using both field studies and simulation to record various traffic parameters for purposes of studying the traffic trends and analyzing the impact of installing a smart road management system. The results of the two tests are as tabulated below:

6.3.2. SIMULATION RESULTS

Simulation was done using Aimsun simulator. It has the ability to conduct microscopic simulation whereby all the parameters were set for the road and the obtained results recorded. A sample screenshot of the parameters that are set is as shown below:

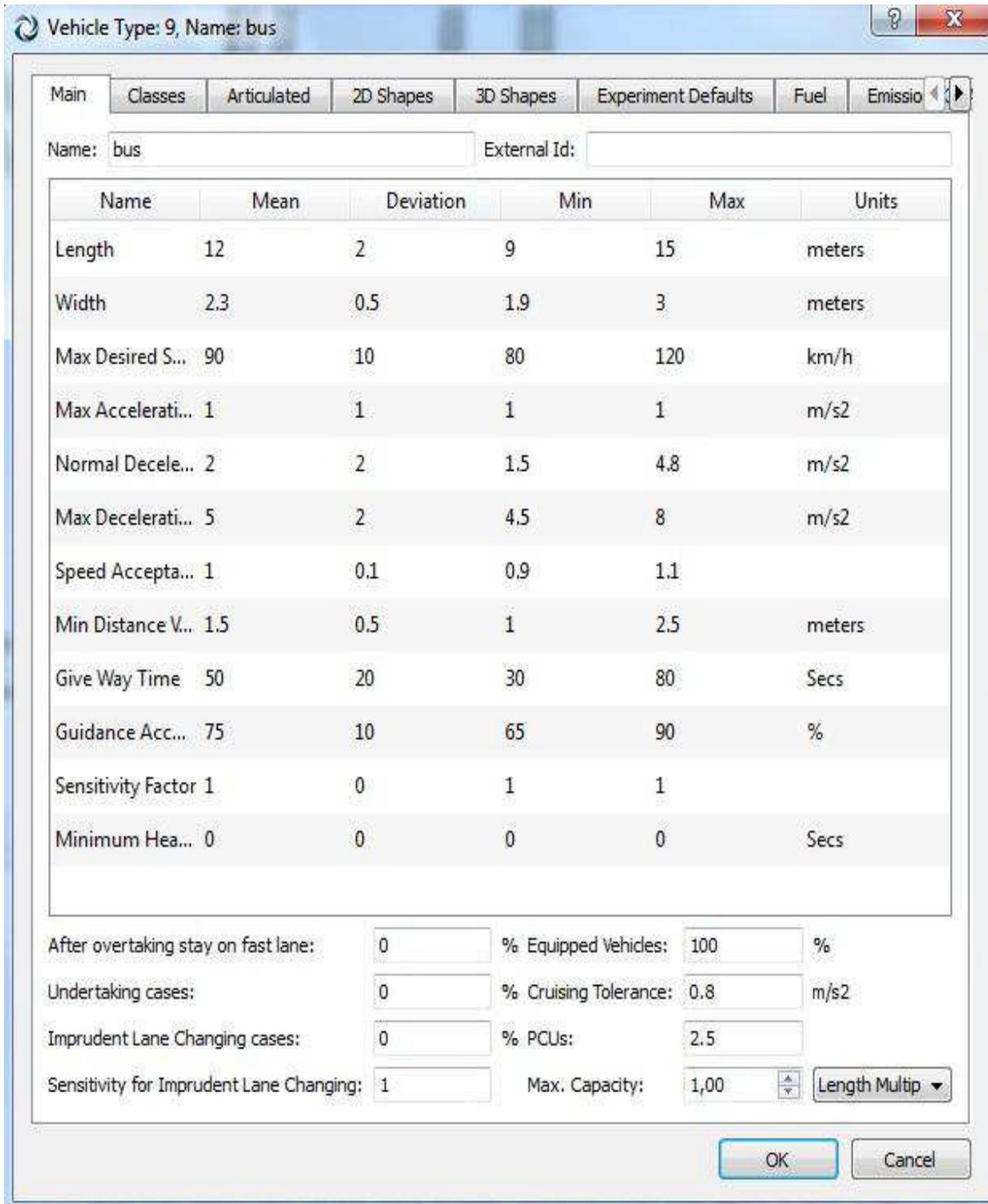


Figure 6.1. Screenshot of parameters setting in Aimsun simulator.

It has the provision to import the Thika road map from Google maps as shown below for use in the analysis of traffic in the sections indicated:

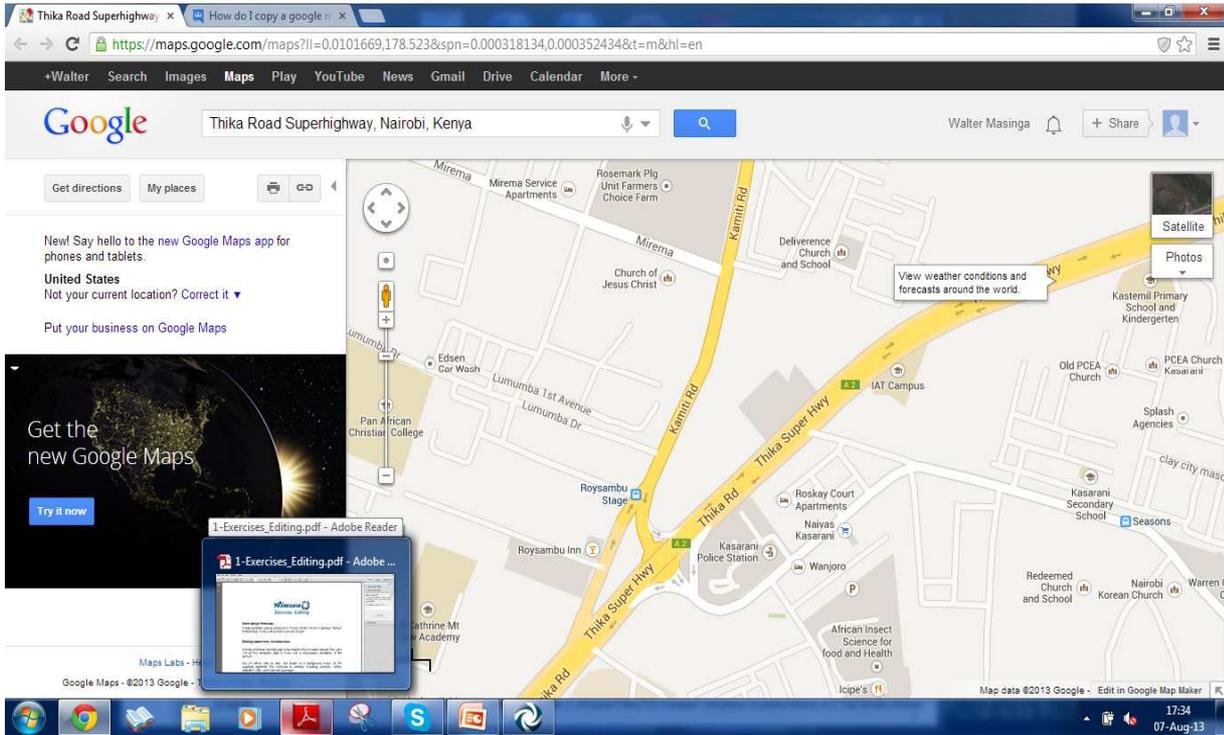


Figure 6.2. A section of Thika superhighway imported from Google maps to the Aimsun simulator.

SUMMARY OF SIMULATED TRAFFIC DATA RESULTS

OBSERVATION POINT	LOCATION	AVERAGE SPEED (KM/HR)	TURNING MVT/MIN	INTERSECTION DELAY IN MINS	DENSITY	FLOW	REMARKS
1	GITHURAI	100	15	2	32	3200	
2	ROYSAMBU	100	15	2	25	2500	
3	ROASTERS	75	10	1	33	2475	
4	ALL SOPPS	70	20	3	32	2240	
5	SURVEY	70	12	2	30	2100	
6	PANGANI	60	20	3	35	2100	
7	NGARA	45	21	3	40	1800	

Table 6.1. Summary of simulated traffic data results

PHYSICAL TRAFFIC DATA RESULTS FOR PEAK PERIODS OF BETWEEN 0600HRS TO 0900HRS

OBSERVATION POINT	LOCATION	AVERAGE SPEED (KM/HR)	TURNING MVT/MIN	INTERSECTION DELAY IN MINS	DENSITY	FLOW	REMARKS
1	GITHURAI	100	10	3	23	2300	
2	ROYSAMBU	90	15	3	25	2250	
3	ROASTERS	80	12	2	25	2000	
4	ALL SOPPS	65	18	4	28	1820	
5	SURVEY	60	15	3	29	1740	
6	PANGANI	60	20	2	30	1800	
7	NGARA	30	25	8	50	1500	

Table 6.2. Physical traffic data for peak hours

PHYSICAL TRAFFIC DATA RESULTS FOR OFF PEAK PERIODS OF BETWEEN 0900HRS TO 1500HRS

OBSERVATION POINT	LOCATION	AVERAGE SPEED (KM/HR)	TURNING MVT/MIN	INTERSECTION DELAY IN MINS	DENSITY	FLOW	REMARKS
1	GITHURAI	100	10	3	20	2000	
2	ROYSAMBU	95	15	3	22	2090	
3	ROASTERS	90	9	2	23	2070	
4	ALL SOPPS	78	10	4	25	1950	
5	SURVEY	73	13	3	25	1825	
6	PANGANI	67	23	1	28	1876	
7	NGARA	50	20	5	30	1500	

Table 6.3. Physical traffic data for off peak hours

COMPARISON OF THE DEVIATION BETWEEN PHYSICAL AND SIMULATED RESULTS.

OBSERVATION POINT	LOCATION	FLOW			TURNING MVT/MIN			INTERSECTION DELAY IN MINS			REMARKS
		PEAK	OFF PEAK	DEVIATION	PEAK	OFF PEAK	DEVIATION	PEAK	OFF PEAK	DEVIATION	
1	GITHURAI	2300	2000	300	10	10	0	3	3	0	
2	ROYSAMBU	2250	2090	160	15	15	0	3	3	0	
3	ROASTERS	2000	2070	70	12	9	2	2	2	0	
4	ALL SOPPS	1820	1950	130	18	10	8	4	4	0	
5	SURVEY	1740	1825	85	15	13	2	3	3	0	
6	PANGANI	1800	1876	76	20	23	-3	2	1	1	
7	NGARA	1500	1500	0	25	20	5	8	5	3	

Table 6.4. Comparison of the deviation between physical and simulated results.

6.3.3. OBSERVATIONS DURING DATA COLLECTION

The data was collected for an average of five minutes over an observation point and then averaged to get a representative sample. There was an exclusion of unique traffic situations like cases of road clearance for presidential motorcade, ambulance activities and other VIP escort activities

The following observations were made:

- An incident on the road drastically and quickly changed the traffic situation at that point which had a spillover effect to adjacent areas. There was instant congestion and reduction of speeds and delays. At some cases the traffic police had to redirect the traffic to alternative routes to reduce the congestion. Therefore it can be deduced that the congestion was occasioned by lack of information by motorists on the road incidents. This would have been reduced by the motorists opting to use alternative routes had they been informed.

- There were seven incidents of collisions with stationary vehicles on the section of the road. Five of these were a few metres from road bends where as two were on straight road stretches.
- 10 Accidents cases were observed during the study and they were reported to the authorities via mobile phones long after casualties had been taken to nearby health facilities by well wishers. This implies that the current system is reactive to incidents where as the proposed system will be proactive by ensuring that emergency response agencies are in the know of any accidents as they happen through the various monitoring and reporting systems.
- The only traffic information about the road situation available was through FM radio stations which were broadcast hourly. This was found to have changed drastically by the time one got to the referred place especially those who were far from the place in question. This implies that the current system is not only insufficient but unreliable since it lacks dedicated public broadcast channels for both radio and TV which can relay information in real time and display changes as they occur.

6.4. DATA ANALYSIS

From the traffic data gathered the following observations can be made:

- The average travel speeds decrease as you move to town. This is because there is an increase in the number of arterial roads linking to the super highway. This also led to increased densities due to injection of more traffic to the highway from the arterial roads.
- The number of turning movements also increases as you move to town due to increase in traffic density. This translates to increase in intersection delays although this is also subject to the specific road architecture at the observation point for example all Roysambu has more delay than survey since it has more intersection linking busier roads than survey.
- The case of Pangani experienced a variation of results due to the road architecture difference characterized by several interchanges which presented motorists with several options when choosing the route to use and there are no major stops there. This therefore implies that with adequate information on the available routes and their traffic states motorists will make appropriate decisions and this will reduce the traffic congestion. This is the aim of the smart road management system.
- There are increased speeds and reduced vehicle densities during off peak hours since few motorists are using the road at that time. Therefore there is better road utilization with reduced intersection delays due to reduced congestion. The system will enable improved decision making hence there will be better utilization of the roadways whereby the motorists will try to avoid congested areas.

- There is variation between the simulated results and the actual data observed on the road. This is because simulation is unable to capture certain aspects which affect traffic like human behavior of both the drivers and pedestrians and this variable therefore affects results since it affects speeds and turning movements and delay since some motorists decide to drive fast and others slowly.

- Therefore a smart road management system is likely to reduce intersection delay times and also affect the turning movements since the drivers will avoid certain intersections which are congested and this will result in an evenly distributed traffic at the intersections hence less congestion and delay. The traffic density and flow will also be changed by the smart system since road users will decide when to travel and which route to use hence no instantaneous build up of traffic due to lack of information.

6.5. ERROR ANALYSIS.

During measurement of data and analysis errors are bound to occur, it is important to understand their impact on the results in order to make informed decision.

The accuracy of a measurement system is established by comparing it with actual data which can be used as a reference value. For the case of traffic analysis the values obtained through simulation are compared with actual figures in order to give the error margin.

From scientific experiments the error margins for various technologies have been established and have been found to be affected by certain factors.

For the detectors used for data collection the speed of vehicles is critical in affecting the accuracy of data gathered with most results being poor for very slow or very fast speeds. Environmental conditions also affect accuracy of the detectors as follows:

- a. Precipitation. It affects the operation of infrared detectors and in cases of fog those that used visible light for detection are affected.
- b. Wind-it affects functioning of ultrasound detectors as it causes turbulence that can distort the ultrasound waveform.
- c. Electromagnetic interference. It affects all types of detectors as it adds noise into the received signal and distorts it. A microwave receiver will be affected by radars operating in the vicinity.
- d. Shadows affect the functioning of CCTV and other video image processors and are likely to affect the video data processing.

The disparity between simulated results and actual results can also be as result of other factors that would not be captured in a simulation model for example the variation of human behavior for both pedestrians and drivers on the particular time and also the impact of instantaneous and unforeseen activities on the road for example clearance of traffic to give way for VIP to pass through.

Adverse weather effects and their effect on the traffic was not adequately addressed since the weather during the time of study was fairly moderate hence lack of its accurate reporting to motorists would only be predicted as being catastrophic for example a motorist plunging into a flood.

6.6. CONCLUSION

ITS will deliver enormous benefits to the transport sector by providing novel ways of managing the transport system and also offering a wide range of services which will enhance the users convenience and efficiency.

A lot of interest has been generated in this area and funds have been allocated for deployment of systems around the world. However the effort is isolated and at times the ICT s used are incompatible albeit with some little efforts of standardization by IEEE. This therefore calls for concerted efforts for harmonization of the ITS systems development so as to achieve synergy and accelerate their development

Another aspect that has been overlooked during the deployment of the system is the realization of the full potential of the ITS system by integrating various operations together as opposed to deployment of individual systems. This is what has been addressed in this research so as to achieve the benefits of cooperative systems.

It is also important to note that there are big strides that have been made in both hardware and software development for use in ITS systems and more research is ongoing. It is therefore likely that smart systems on the roads will become a reality in the near future.

This system is feasible as it utilizes technologies that have been tested and are currently in use and it is recommended that it be deployed in the city as a pilot project and later on rolled out to the rest of the country when funds become available.

6.7. FUTURE WORK

A lot more can be achieved by use of ITS on the road network and a lot of areas still need further study and utilization in line with the advance in technology. Some of the areas that can be further explored include the following:

- a. Smart passenger and public service vehicle management where by ICT should be considered for fare payment and interaction between the passenger and the vehicles for real time transactions and information exchange.
- b. More work can be done in integrating the real time traffic information with the transport system actuator systems like the traffic lights, road blocks and the vehicle control systems. This will ensure compliance with the traffic regulations and also improved control of the traffic in the roads. This will involve more research in the design on the equipments to make them compatible with the output of the ITS system and also development of programs to implement such systems.

6.8. RECOMMENDATIONS

It is recommended that for a robust system to be implemented a lot of consideration be given to the following:

- Ensure that mature technologies are employed so as to guarantee accurate and reliable results.
- Standardization of data handling, protocols for connection and data transmission to be in place for seamless transmission.
- The system must be designed so as to be scalable, this will allow for piecemeal system implementation which is suitable for cases where funds are limited. This will also be good for system upgrade, improvement or enhancement of functionality or area of coverage.
- The common user should be trained on utilization of the system to achieve maximum results and this requires that all the road users be ICT compliant. Therefore policy and effort should be made towards ICT skills training for motorists.
- Upon successful implementation then other transport sectors can use a similar system with variation of features and utilities.

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