UNIVERSITY OF STELLENBOSCH

A stepwise approach towards achieving a Multimodal Platform within the context of the CoCT's Land Transport Networks

March 2013

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This thesis is presented in fulfilment of the requirements for the degree of Master of Science in the Department of Civil Engineering at Stellenbosch University.

"Nothing else can breach the apartheid barriers of this city faster and better than integrated public transport. Nor is there any other undertaking that can create, even in the medium term, more jobs, ease the life of the poorest of the poor, and allow them also to share in the natural glories of this city," said Western Cape Transport and Public Works Minister Robin Carlisle.

(McKenzie 2012)

DECLARATIONS

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ABSTRACT

The importance of transport should not be underestimated. Transport progresses a person's quality of life: it connects people to one another and provides access to work, services and recreational opportunities. However, post-apartheid South Africa is unfortunately still faced with a legacy of segregation. While the less-privileged, who mostly live at the fringe of Central Business Districts (CBDs), are captive users of public transport, the private vehicle trend, under the privileged, is becoming more evident.

This research project thus proposes that a balanced and integrated sustainable transport system be promoted. That is, one that will aid South Africa in growing and improving its general socio-economical status by providing all its citizens with (equal) access to a balanced transport network. It is believed that, if a multimodal system is promoted, the deficiencies of the current heterogeneous non-integrated systems may be overcome. Therefore, if South Africa's transport network is augmented with a multimodal platform, the nation will be able to move its citizens effectively and efficiently, without jeopardising the economy, social matters and the environment, today and in the future. Moreover, South Africa will also have the necessary stimulus to utilise the already available resources at its disposal by working together as 'one'.

This research project thus stipulates a (generic) sequential approach needed in achieving an integrated (sustainable) public transport system. The goal of this research project is to create awareness of the benefits that may arise from, and the implementation steps required in obtaining, such a multimodal platform. The focus area for researching the proposition made herein is the City of Cape Town's (CoCT's) land transport networks. The City has a management facility, with resultant transport data repository, known as the Transport Management Centre (TMC). This TMC is regarded as one of the finest state of the art facilities in the world and the features thereof offer a sufficient base and point of departure for the promotion of a multimodal transport system.

By conducting research in this field, the following portraying aspects, needed for the realisation of the proposition made herein, were found.

Firstly, in order to obtain an integrated sustainable transport system, the appropriate Intelligent Transport Systems (ITS) need to be integrated. It is believed that, if an intelligent transport scheme, grounded on ITS applications, is advocated, the City will be in the position to more effectively monitor what is going on, to more accurately predict what might happen in the future, and to manage its transport system proactively on an area-wide basis.

Secondly, in order to meet the integration requirements imposed by multimodal transport, a centralised database needs to be created. With such a database in place, information sharing across all modes of private- and public land transport, and thus also between the investors or the operators, will be possible. An example of such a database was developed in Microsoft Access and the modes considered therein are: MyCiti, Metrorail and Golden Arrow Bus Service (GABS). The data stored in this database is historic, but the incorporation of real time information was also catered for.

Thirdly, it is believed that the success of the City's transport system, and the development of a multimodal system, is dependent on the provision of an efficient Advanced Traveller Information System (ATIS). The idea is to promote multimodal transport as a convenient transit option by providing travellers with information on journey planning that aims to counteract their reluctance to change. In order to develop such a multimodal Journey Planner (JP), the unimodal networks considered herein were combined into a supernetwork on which Dijkstra's Shortest Path Algorithm was applied. This algorithm was programmed in Microsoft Excel's Visual Basic for Applications (VBA) and it incorporates the following user criteria: the origin, the destination, the user's mode preference, and the user's optimisation preference of either time or distance.

In conclusion, it can be argued that, with information becoming such a vital commodity in everyday life, the catering for informed travellers are the key to successful future transport services. If travellers are informed about the transport networks' performance, a positive attitude is fostered. Moreover, by providing travellers with information on journey planning, their feelings of uncertainty and fear of the unknown, that are present in (especially) public transport services, may be neutralised. This information will give the public carte blanche to make decisions that give them the perception of having more 'control over their lives'. Therefore, if a multimodal JP that can be accessed from one portal is created, people's inclination to acquire more information will be met. And as a result, traversing in an integrated manner may become the norm.

OPSOMMING

Die belangrikheid van vervoer mag nie onderskat word nie. Vervoer speel ’n belangrike rol in die bevordering van ’n persoon se lewenskwaliteit: dit verbind mense met mekaar en verskaf toegang tot die werksplek, diensteverskaffers, en vryetydsbesteding. Post-apartheid Suid-Afrika is egter nog steeds vasgevang in ’n nalatenskap van rasseskeiding. Die minderbevoorregtes, wat meestal aan die buitewyke van die stad woon, is geforseerde gebruikers van openbare vervoer, terwyl die neiging (onder die bevoorregtes) om privaatvoertuie te gebruik, aan die toeneem is.

Hierdie navorsingsprojek beveel dus aan dat ’n gebalanseerde, geïntegreerde en volhoubare vervoerstelsel bevorder moet word. ’n Sodanige stelsel sal help om die sosio-ekonomiese status van Suid-Afrika te bevorder. Dít kan net bereik word as alle landsburgers gelyke toegang tot ’n gebalanseeerde vervoernetwerk het. As ’n multimode-stelsel dus bevorder word, kan die tekortkominge van die huidige heterogene, nie-geïntegreerde stelsels oorkom word. Indien Suid-Afrika se vervoernetwerk ’n multimodale platform het, kan die landsburgers effektief en doeltreffend vervoer word sonder om die ekonomie, sosiale aangeleenthede of omgewing, tans en in die toekoms, in gedrang in te bring. Suid-Afrika sal boonop, met so ’n platform in plek, ook die nodige stimulus hê om die bestaande hulpbronne optimaal te gebruik.

Hierdie navorsingsprojek verskaf ’n (generiese) in-volgorde-benadering om ’n volhoubare, geïntegreerde openbare vervoerstelsel daar te stel. Die doel is om bewustheid van die voordele wat uit ’n multimodale platform spruit, sowel as die nodige stappe vir die uitvoering daarvan, te kweek. Die fokusarea van die navorsing is die Stad van Kaapstad se land-vervoernetwerke. Die Stad het ’n beheerfasiliteit waar vervoerdata versamel word. Dit staan bekend as die vervoer-beheersentrum (TMC: Transport Management Centre). Hierdie fasiliteit word as toonaangewend in die wêreld beskou. Die kenmerkende eienskappe van hierdie fasiliteit bied verder ook ’n goeie vertrekpunt vir die bevordering van ’n multimodale stelsel.

Die navorsing in hierdie veld het die volgende bydraende faktore, wat benodig word om die voorstelling te realiseer, geïdentifiseer.

In die eerste plek moet die intelligente vervoerstelsels (ITS: Intelligent Transport Systems) geïntegreer word om ’n geïntegreerde volhoubare vervoerstelsel daar te stel. Indien ’n intelligente vervoerskema, gebaseer op tegnologiese inisiatiewe, aangemoedig word, sal die Stad van Kaapstad in die posisie wees om sy vervoerstelsel pro-aktief te bestuur deur meer effektief te monitor wat aangaan en meer akkuraat te voorspel wat in die toekoms mag gebeur.

Tweedens moet daar ’n gesentraliseerde databasis geskep word. Met hierdie databasis sal die nodige integrasievereistes vir ’n multimodale vervoerstelsel, bereik word. Inligting kan dan gedeel word tussen privaat- en openbare landvervoer, asook tussen die beleggers en die operateurs van die verskillende vervoermodusse. ’n Voorbeeld van so ’n databasis is in Microsoft Access geskep en die modusse wat deel daarvan uitmaak, is: MyCiti, Metrorail en Golden Arrow Bus Services (GABS). Die data wat hierin vervat is, is histories, maar daar is vir intydse inligting voorsiening gemaak.

In die derde plek is die sukses van die Stad van Kaapstad se vervoerstelsel en die ontwikkeling van ’n multimodale stelsel afhanklik van die daarstelling van ’n effektiewe, gevorderde inligtingsstelsel vir pendelaars (ATIS: Advanced Traveller Information Systems). Die idee is om ’n multimodale vervoerstelsel as ’n gerieflike opsie onder pendelaars te bevorder. Dit kan bereik word deur inligting rakende reisbeplanning aan pendelaars daar te stel. Met die verkryging van sodanige kennis sal die pendelaar se weerstand teen verandering ook afneem. Om so ’n multimodale reisbeplanner (JP: Journey Planner) te ontwikkel, is die eenmodaal-netwerke gekombineer om ’n supernetwerk te skep. Dijkstra se algoritme is op die supernetwerk toegepas. Die algoritme is in Microsoft Excel se VBA (Visual Basic for Applications) geprogrammeer en dit bevat die volgende gebruikerskriteria, nl. die begin- en eindpunt, die gebruiker se modes-voorkeur en die gebruiker se gekose optimeringsvoorkeur van tyd of afstand.

Ten slotte kan gesê word dat inligting ’n groot rol in die mens se daaglikse lewe en aktiwiteite speel. Daar kan dus geredeneer word dat die sleutel tot suksesvolle vervoerdienste daarin lê om vir ingeligte pendelaars voorsiening te maak. As pendelaars ingelig is oor die stand van die vervoernetwerk maak dit hul houding meer positief. Verder, as pendelaars ook inligting oor reisbeplanning het, kan dit hul gevoel van onsekerheid en vrees jeens (veral) openbare vervoer teenwerk. Met al hierdie inligting tot sy beskikking kan ’n persoon dus sy eie keuses maak en dit lei daartoe dat die persoon meer in beheer voel. As ’n multimodale JP geskep word, voed dit die mens se begeerte vir meer inligting. En met ’n sodanige JP in plek, kan geïntegreerde pendel moontlik die norm word.

ACKNOWLEDGEMENTS

I am heartily thankful to my supervisors, Professor Christo Bester and Doctor Johann Andersen, whose encouragement, guidance and support from the initial to the final level, enabled me to develop a profound understanding of this thesis subject.

Furthermore, it is an honour for me to thank Judy Scott, who provided me with very insightful and important data. I am very grateful for her help and efforts.

I also owe my deepest gratitude to Zander Bingle, Database Consultant, without whom this research project would not have been possible. He has made available his support in a number of ways and gave me hope in times I felt despondent.

Additionally, I would like to sincerely thank Lovia Delport, Graphic Designer, who open-heartedly assisted me with stimulating and creative ideas on designs.

And lastly, I offer my regards and blessings to all of those who supported me in any respect during the completion of this research project, especially my parents Anton and Mariëtte Struwig.

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ACRONYMS/ABBREVIATIONS

AFC: Automated Fare Collection

AMS: Arterial Management Systems

APTS: Advanced Public Transport Systems

ASCII: American Standard Code for Information Interchange

ATIS: Advanced Traveller Information Systems

ATMS: Advanced Traffic Management Systems

AVL: Automated Vehicle Location

BC: Benefit-Cost

BRT: Bus Rapid Transit

CBD: Central Business District

CCTV: Closed Circuit Television

CH: Contraction Hierarchies

CoCT: City of Cape Town

CPTR: Current Public Transport Records

CRPQ: Conjunctive Regular Path Query

CTC: Centralised Traffic Control

CSV: Comma Separated Values

CQ: Conjunctive Query

DB: Database

DBA: Database Administrator

DBO: Database Owner

DBMS: Database Management System

DCL: Data Control Language

DDL: Data Definition Language

DM: Data Mart

DML: Data Manipulation Language

DoT: Department of Transport

DRegLC: Dijkstra's Regular Language Constrained

DRT: Department of Roads and Transport

DSRC: Dedicated Short Range Communications

DW: Data Warehouse

EFP: Electronic Fare Payment

EMV: Europay, MasterCard and Visa

ER: Entity-Relationship

FHWA: Federal Highway Administration

FIFA: Fédération Internationale de Football Association

FMS: Freeway Management Systems

GABS: Golden Arrow Bus Services

GC: Generalised-Cost

GDP: Gross Domestic Product

GDRT: Gauteng Department of Roads and Transport

GE: Google Earth

GIS: Geographical Information System

GPS: Global Positioning System

GRP: Gross Regional Product

GRS80: Geodetic Reference System 1980

GUI: Graphic User Interface

HAR: Highway Advisory Radio

HD: High Definition

HTML: HyperText Markup Language

HTTP: HyperText Transfer Protocol

IC: Integrity Constraints

ID: Identification

IFM: Interoperable Fare Management

IIM: Integrated Incident Management

IMS: Incident Management Systems

IMTI: Integrated Multimodal Traveller Information

IRPTN: Integrated Rapid Public Transport Network

IRT: Integrated Rapid Transport

ISO: International Organization for Standardization

IT: Information Technology

ITMS: Integrated Transport Management System

ITP: Integrated Transport Plan

ITS: Intelligent Transport Systems

JP: Journey Planner

KML: Keyhole Mark-up Language

LAN: Local Area Network

LCSPP: Language Constrained Shortest Path Problem

LOS: Level of Service

MDA: Multi-Dimensional Analytical

MEC: Member of the Executive Council

MS: Microsoft

NF: Normal Form

NHS: National Household Survey

NLTTA: National land Transport Transition Act

NMT: Non-Motorised Transport

NPV: Net Present Value

OD: Origin-Destination

ODS: Operational Data Store

OLAP: OnLine Analytic Processing

OLTP: OnLine Transaction Processing

PC: Personal Computer

PDA: Personal Digital Assistant

PDF: Portable Document Format

PGWC: Provincial Government of Western Cape

POS: Point of Sale

PRASA: Passenger Rail Agency of South Africa

PTN: Public Transport Network

PVN: Private Vehicle Network

RegLCSP: Regular Language Constrained Shortest Path

RF: Radio Frequency

RFID: Radio-Frequency Identification

RPQ: Regular Path Query

RSA: Republic of South Africa

SABS: South African Bureau of Standards

SANRAL: South African National Roads Agency Limited

SAPS: South African Police Service

SP: Stored Procedure

SPP: Shortest Path Problem

SQL: Structured Query Language

SV: Sedgewick-Vitter

TCP/IP: Transmission Control Protocol/Internet Protocol

TDM: Travel Demand Management

TIC: Transport Information Centre

TMC: Transport Management Centre

TOC: Traffic Operations Centre

TRS: Transport Reporting System

TV: Television

UCT: University of Cape Town

UTC: Urban Traffic Control

VBA: Visual Basic for Applications

VMS: Variable Message Signs

1. INTRODUCTION

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1.1 BACKGROUND TO SA'S TRANSPORT NETWORK - WITH SPECIFIC FOCUS ON THE COCT

A general definition of transport is: the movement of people and goods from one place to another. Transport connects people to one another and provides access to work, services and recreational opportunities (CoCT 2009). An effective and efficient transport network progresses a person's quality of life and thus forms the basis for a country's economic- and social growth.

South Africa is a developing country that, because of the remaining apartheid legacy, still struggles with poverty and inequality. The remaining segregation, repression and subjugation, that post-apartheid South Africa faces, make the provision of equal access to basic amenities (such as transport) difficult. A prevalent gap between the privileged and the less-privileged, with the latter making up the largest percentage of the population, is still clearly visible. Furthermore, due to the spatial condition enforced during the nation's apartheid regime, the less privileged are captive users of public transport. They are mostly located at the fringe of cities whereas the employment opportunities are located in Central Business Districts (CBDs) or in other commercial and industrial nodes (CoCT 2009).

Public transport in South Africa largely consists of minibus taxis, metered-taxis, buses and trains, with the first three modes mentioned being obliged to share the road network with the private vehicle. Consequently, even though the City of Cape Town (CoCT) has an extensive road network, the City is, with its traffic volume growing steadily per annum, faced with rising capacity constraints among the major links in its road network (CoCT 2009). This not only puts pressure on the road infrastructure, but also affects the City's land use- and travel demand management.

Fortunately, with the honour bestowed upon South Africa of hosting the FIFA World Cup 2010, the Government took its chance to spur a major revolution in South Africa's transport network (RSA DoT 2006). In 2007 the Government introduced the National Land Transport Transition Act (NLTTA) in which the minimum requirements for the nation's Integrated Transport Plans (ITPs) are stipulated (RSA DoT 2007). As part of these minimum requirements, the Government emphasised the importance of developing an efficient (and/or improving the nation's existing) public transport network.

The Department of Transport (DoT) identified 12 cities to act as the planning authorities and instigation bodies in developing their respective ITPs (RSA DoT 2007). In 2009, the CoCT announced their ITP which gave rise to the City's Integrated Rapid Public Transport Network (IRPTN) (CoCT 2009). The City's IRPTN is known as MyCiti and the starter phase thereof was launched in May 2011 (Luhanga 2011).

By investing in public transport, the Government aims to make public transport a preferable means of transit. Firstly, the travel time on public transport modes (such as train or rapid transport) is likely to be far less than the travel time by private vehicle, especially for parts of a journey where congestion is likely to occur (Dziekan and Dicke-Ogenia 2010). Secondly, public transport is considered to be a space efficient mode of transport, because more passengers per unit of road space occupied, can be transported (Kasturia and Verma 2010). Therefore, the idea is to not only promote public transport as a convenient mode of transport, but also as an environment-friendly transport mode choice.

1.2 A SUSTAINABLE FUTURE FOR SOUTH AFRICA

1.2.1 AN INTEGRATED TRANSPORT MANAGEMENT SYSTEM

In order for a developing country like South Africa to improve its general socio-economical standard, the importance of providing all its citizens with (equal) access to a balanced land transport network (specifically public transport) cannot be over emphasised.

With the establishment of the NLTTA in 2007, the nation has actively started to promote access to mobility and treats it as one of the basic and/or fundamental human rights. However, with the increase in implementation mandates, South Africa's public transport system is facing new challenges and proper management thereof is needed. Some of the problems that the Gauteng province currently faces are: duplication of some services, utilisation of inappropriate modes on certain routes, violence in some sectors of the public transport network and other problems experienced with regulation and control (GDRT 2011). This author believes this to be the case for all the other provinces that has started promoting and investing in public transport.

The nation is faced with the following predicament: THE MERE PROVISION AND/OR ENHANCEMENT OF THE EXISTING (PUBLIC) LAND TRANSPORT NETWORK IS NOT SUFFICIENT TO INDUCE A SUSTAINABLE (PUBLIC) LAND TRANSPORT SYSTEM. Moreover, as South Africa's population keeps growing and the nation hence becomes denser, the protruding need for providing its citizens with sustainable mobility also becomes apparent (GDRT 2011). CoCT (2009) defines sustainable transport as follows:

> "SUSTAINABLE TRANSPORT IS THE ABILITY TO MOVE PEOPLE AND GOODS EFFECTIVELY, EFFICIENTLY, SAFELY AND MOST AFFORDABLY, WITHOUT JEOPARDISING THE **ECONOMY**, **SOCIAL MATTERS** AND THE **ENVIRONMENT,** TODAY AND INTO THE FUTURE."

This author believes that, if South Africa however commences with the promotion of an Integrated Transport Management System (ITMS), it will give rise to the necessary innovative development needed in upholding a sustainable transport system.

According to Turnbull (2001), an ITMS will provide for the real time sharing of information as well as the coordination of management activities between transport agencies. Consequently, enabling an area-wide view of the transport network. This will not only enhance system interoperability, but will also aid the nation in resolving its transport problems caused by the multi-jurisdictional, multi-agency, and multi-disciplinary institutional frameworks currently in place. Furthermore, in our IT driven world, it can be assumed that, information and technology are available and accessible to all. Intelligent Transport Systems (ITS) are being incorporated into transport solutions more and more, and the realisation of Transport Management Centres (TMCs) is happening now.

The ITMS initiative, in conjunction with these emerging and evolving information technologies, have undoubtedly developed new avenues and have made provision for the establishment and realisation of the proposition made herein. That is, the promotion of a multimodal transport system.

1.2.2 A MULTIMODAL TRANSPORT SYSTEM

The coordination and cooperation of systems and agencies, resulting from an ITMS, will provide for the management and operation of a variety of different transport facilities and -functions, including, among others: freeways, arterial roads, transit (e.g. bus and rail), emergency service providers and information service providers (Turnbull 2001).

It is therefore evident that, by promoting an ITMS, the sharing of information among government agencies and private- and public sectors, will accordingly, also realise. And with such an (open) information platform in place, the concept of modal integration is fostered.

GDRT (2011) defines modal integration as follows:

> "MODAL INTEGRATION IS THE COMBINATION OF ALL MODES OF TRAVEL (PRIVATE- AND PUBLIC TRANSPORT AS WELL AS NON-MOTORISED TRANSPORT SUCH AS CYCLING, WALKING) INTO AN INTERDEPENDENT AND INTEGRATED TRANSPORT SYSTEM, OPTIMISED IN TERMS OF AFFORDABILITY, EFFECTIVENESS AND EFFICIENCY, INCLUDING REAL OPERATING, MAINTENANCE AND CAPITAL COSTS."

The goal of modal integration is thus to achieve an integrated transport network and -system in which all modes of land transport operate in a single seamless system within an integrated network; with integrated schedules; with proper transfer facilities; with a common ticketing- and fare system, including through ticketing[1], and with a combined information system, including transport information centres (GDRT 2011).

GDRT (2011) developed five measures to be used in the management of a modal integrated transport network and -system. These measures are:

1. Physical integration: the close proximity of, and ease of access at, modal interchange points.
2. Network integration: the provision of an integrated network in which each separate network complements each other.
3. Information integration: the provision of travel time- and trip information to travellers.
4. Fare integration: the provision of a single fare card that facilitates the transfer between different modes of transport for multiple transit services.
5. Institution integration: the cooperation and coordination among government agencies and between the private- and public sectors.

The first two measures mentioned relate to 'infrastructure integration' and are thus important measures to be considered in achieving an integrated transport network. However, as mentioned previously, the mere provision of an integrated transport network is not sufficient to induce a sustainable transport system. Therefore, this author believes that, the principal success factor in attaining multimodal transport is: information integration. However, information integration cannot be achieved without executing both fare- and institution integration. Institution integration will enable information integration, which will in effect facilitate the provision of comprehensive travel information. As a result, all citizens will be in the position to become

[1] Transfer tickets that enable travellers to transfer from one route to another to complete their journeys. There is, however, usually a time limit, typically one hour or 90 minutes after the initial purchase or validation, within which the second journey must start.

intelligent (i.e. informed) travellers. Furthermore, with the aid of fare integration, the citizens' attitude towards public transport may change for the better. That is, if the citizens are provided with a more convenient public transport service, they may start to view public transport as their preferable means of transit.

1.3 THE RESEARCH PROPOSITION

Based on the aforementioned research, it is proposed that a multimodal transport system be promoted. It is believed that, with the attainment of this proposition, a balanced and integrated sustainable transport system, to which all citizens have (equal) access, may follow.

As mentioned previously, it is recognised that a multimodal transport system will result in: physical-, network-, information-, fare-, and institution integration. Therefore, by promoting a multimodal transport system, South Africa will have the necessary stimulus to utilise the already available resources at its disposal and the nation will, accordingly, be in the position to overcome the deficiencies of its current heterogeneous non-integrated systems. Furthermore, due to multimodal transport's believed contribution to the socio-economical standard of a nation, South Africa will, optimally, be able to move its citizens effectively and efficiently, without jeopardising the economy, social matters and the environment, today and in the future.

The goal of this research project is to create awareness of the benefits that may arise from, and the implementation steps required in obtaining, a balanced and integrated sustainable transport system. However, due to the multi-jurisdictional, multi-agency, and multi-disciplinary institutional frameworks currently in place, the enormity and complexity of the proposition made herein, are evident. It is therefore proposed that a simplistic approach, to the attainment of a multimodal platform, be researched. The objective of this research project is to develop a generic (sequential) framework for the implementation of multimodal transport, with the focus area for testing its logical application, being the City of Cape Town's (CoCT's) land transport networks.

1.4 THE LAYOUT OF THE RESEARCH PROJECT

Section 2: Literature Review

> This section provides an overview of the portraying aspects needed in attaining a balanced and integrated sustainable transport system. Firstly, an introduction to the vast and eminent nature of today's transport networks, that amplifies their complexity, their large scale application, and thus also their design, is given. Secondly, an introduction to multimodal transport is given. Specific focus is placed on its implementation barriers and the travellers' relevant information needs when commuting in such a system. Then,

following from the evident complex transport environment, a technology approach, in attaining a multimodal platform, is stipulated. That is, how technology can be used to obtain data, how the data can be transformed to information that is valued by the traveller, and how to present this information in a manner most suitable to the traveller. Lastly, the possible benefits resulting from a multimodal transport system are discussed.

Section 3: Status Quo

In this section, market research, on what is currently at the CoCT's disposal, is conducted. This section accordingly considers the status of the CoCT's land transport networks, its transport management facility, the transport reporting system used by the City's Transport Department, and lastly, the current travel information available to the travellers.

Section 4: Research Design

This section considers, in detail, a discussion of all the portraying aspects required in obtaining multimodal transport. The main aspects considered are: 1) the multimodal transport network and the design and modelling thereof, 2) the role of Intelligent Transport Systems (ITS) in achieving a multimodal platform, 3) the need for and the design criteria of a (centralised) database, and 4) the need for and the travel information requirements of a multimodal Journey Planner (JP). This section then concludes with integrating all these aspects, in order to develop a generic (sequential) framework for the implementation of multimodal transport.

Section 5: Research Methodology

In this section, the sequential steps concluded from the previous section, are used as a point of reference for implementing a multimodal platform. The logical application of the generic (sequential) framework developed is then tested on the CoCT's land transport networks.

Section 6: Results

This section gives a summary of the implementation steps used in obtaining a multimodal platform. Furthermore, the proposed solution is also compared to the current practice followed. And lastly, the recommended way forward is discussed.

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2.1 SUSTAINABLE TRANSPORT DEVELOPMENT

Due to the important role that transport plays in the general development of a nation's socio-economical standard, the protruding need to cater for sustainable mobility is becoming unmistakable (GDRT 2011). Sustainable transport development is based on the concept of integrating economic-, social- and environmental sustainability. Figure 1 (Vanderschuren 2006) depicts the requirements of the transport services, with respect to each of these sustainable measures, associated with the achievement of sustainable transport development.

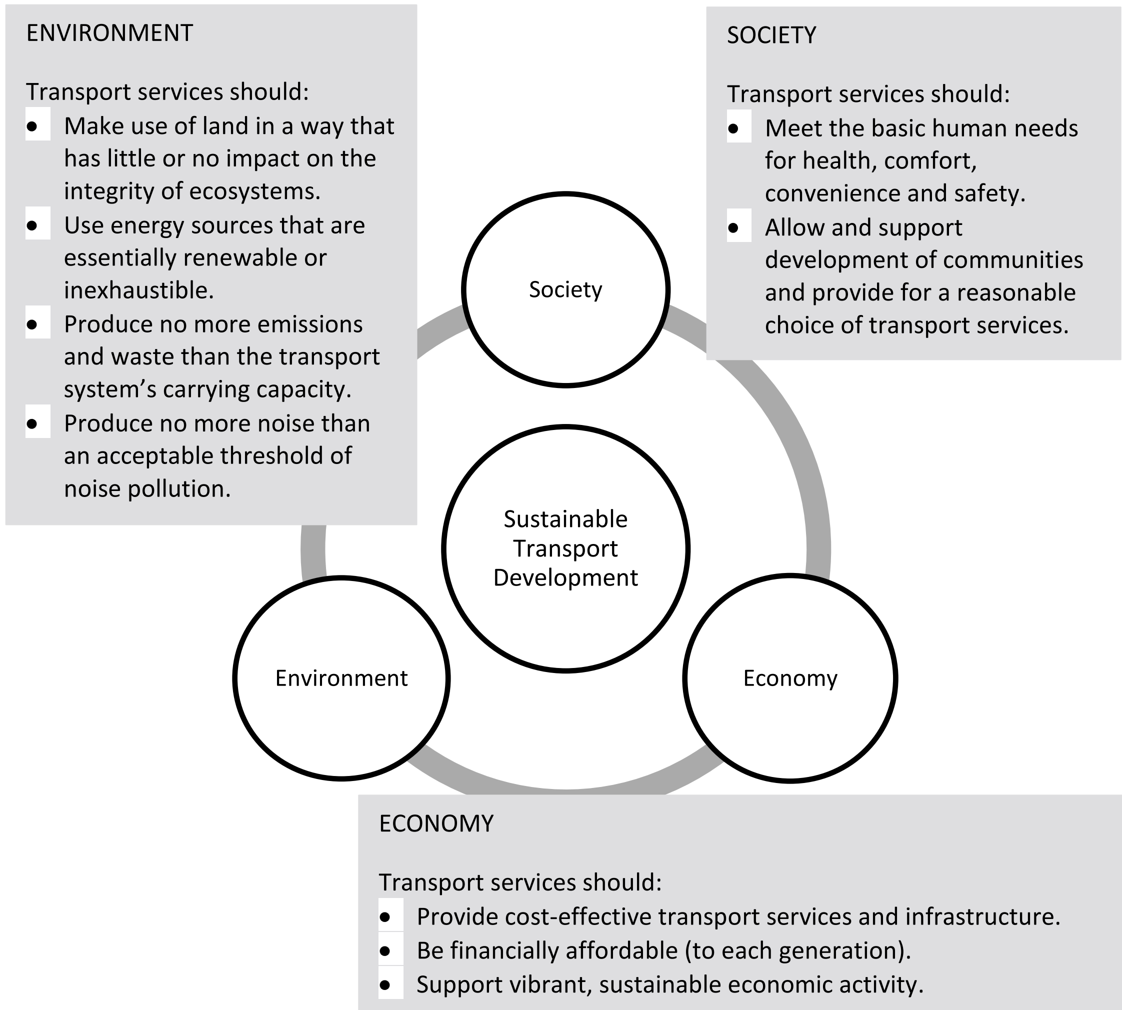

FIGURE 1: SUSTAINABLE TRANSPORT DEVELOPMENT

According to Rehrl *et al.* (2007), if a shift towards multimodal transport is made, a high level of mobility in the long term (i.e. sustainable mobility) can be achieved. By combining private- and public transport into a multimodal transport system, opportunities to capitalise on the strengths of the various systems, while avoiding their weaknesses, are possible (Van Nes 2002). Therefore, this author believes that, if South Africa utilises its current resources optimally, that is, integrating its existing transport networks, the nation will be in the position to attain a sustainable transport system. Furthermore, by promoting an interoperable multimodal transport system, not only will the mobility of the nation's citizens be improved, but the access to the transport network may also, as a result, be improved. Optimally, South Africa will be able to move its citizens effectively and efficiently, without jeopardising the economy, social matter and the environment, today and in the future.

2.2 TRANSPORT NETWORKS

2.2.1 INTRODUCTION

Networks provide the infrastructure for connectivity and hence form the basis for the functioning of our modern economies and societies (Nagurney and Smith 2011):

- Transport networks give people the means for mobility and the shipment and delivery of goods.
- Telecommunication networks of today allow for the spread of information at speeds never before imagined.
- Logistical networks enable the manufacture of products and their delivery to points of demand across the whole world.

2.2.2 THE NETWORK CATEGORIES

A transport network facilitates the making of a trip from an origin to a destination, for a specific mode, and thus determines the characteristics of that trip. Van Nes (2002) considered two categories of transport networks, namely:

- Transport service networks (such as a bus service network or a train service network).
- Traffic service networks or physical networks (such as a road network or a railroad network).

2.2.3 THE NETWORK DESCRIPTION

According to Van Nes (2002), a network is most commonly defined as a set of nodes together with a set of links, where each link connects a pair of nodes. This type of description is especially suited for the modelling of transport networks as it describes all kinds of transport networks (i.e. private or public) found in practice.

In the case of private transport networks, the road network representation includes nodes that model the intersections and links that depict the road segments. And in the case of public transport networks, the representation includes entry- and exit nodes (or access- and egress nodes), transfer nodes (i.e. nodes that represent crossings where no access or egress is possible), public transport lines (i.e. a set of connected links and their nodes) and the associated service frequencies determined from the applicable timetables (Van Nes 2002).

2.2.4 THE NETWORK CHARACTERISTICS

Network characteristics can be seen from two points of view: that of the network user (i.e. traveller) and that of the network investor or network operator (i.e. the stakeholder). An illustration of the difference in an optimal network structure from the traveller's and the investor's point of view can be seen in Figure 2 (Van Nes 2002).

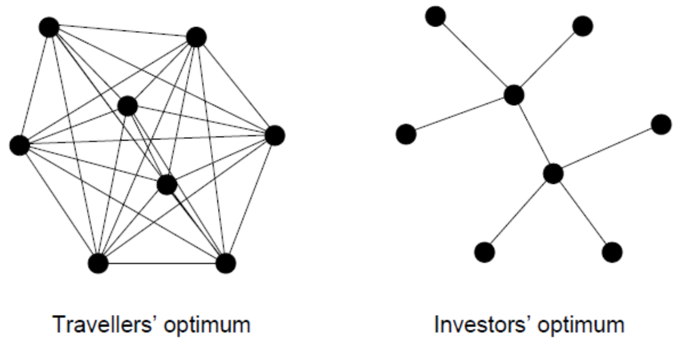

FIGURE 2: TRAVELLER'S VERSUS OPERATOR'S NETWORK OPTIMUM

As can be seen in Figure 2 (Van Nes 2002), it is evident that a traveller prefers direct connections between any origin and destination (and if time accessibility also plays a role, at any time); whereas an investor or operator favours a minimal network in space and in time.

Therefore, from an investor's or operator's perspective, where efficiency plays a key role, costs are clearly the main network characteristic. Van Nes (2002) distinguished three costs, namely; investment cost, maintenance cost and operating cost. And from a traveller's point of view, the main network characteristics are: travel costs and travel time. As stated in Van Nes (2002), travel time is determined by network characteristics such as space accessibility, time accessibility and network speed. A description of each follows.

- <u>Space accessibility</u> refers to the number and distribution of access points where the traveller can enter and leave the network.

- Time accessibility refers to the distribution of opportunities per unit of time for the traveller to use the network.
- Network speed refers to the average speed while travelling on the network, which is determined by the network structure and the design speed. Moreover, since speed is independent of the distance travelled, in some cases, it is preferred over the perhaps more obvious alternative of travel time.

Evidently, a conflict between the traveller's and the investor's (or operator's) viewpoints exists. This will be discussed through a Stackelberg game in the following section.

2.2.5 THE NETWORK DESIGN PROBLEM

The transport network design problem can be illustrated through the following example (Van Nes 2002):

> Assume a set of four nodes (i.e. N = 4) that allows for six (calculated as $\binom{N}{2}$, read as N combination two) possible links between them. The question then is: which links should be included in the network? In order to connect all four nodes, a minimum of three (N-1) links is required. Therefore, all networks consisting of three, four, five, or six links are possible. This results in 42 possible networks: $_{i=3}^{6}\binom{6}{i}$. By applying the same methodology for a set of six nodes (i.e. N = 6) with 15 ($\binom{N}{2}$) possible links, 30 827 networks are possible.

From this numerical example it can clearly be deducted that the number of possible solutions increases more than exponentially as the size of the network grows. Apart from this combinatorial nature, Van Nes (2002) identified two other aspects that increase the complexity of the transport network design problem. The first is a result of the conflict between the viewpoints of the traveller and the investor or operator. As mentioned previously, a traveller prefers direct connections between his/her origin- and destination points, and, if time accessibility also plays a role, at any time; whereas an investor or operator favours a minimal network in space, and in time, thus reducing all cost factors. The second aspect follows from the fact that a traveller's behaviour is strongly interrelated with the design- and operation efficiency of transport networks: changes in the transport network, can lead to changes in a traveller's behaviour. Van Nes (2002) stated that this network design problem can be represented through a Stackelberg game. Refer to Figure 3 (Van Nes 2002).

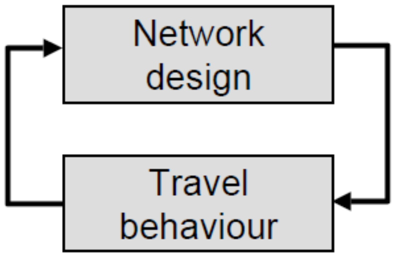

FIGURE 3: THE NETWORK DESIGN PROBLEM AS A STACKELBERG GAME

In a Stackelberg game, two problem types can be distinguished. Based on Figure 3 (Van Nes 2002), it can be defined as follows: the upper problem is the actual design objective in which the optimal network characteristics are determined given usage of the network by the travellers, while the lower problem describes travellers' behaviour given the network that is supplied.

A typical example of this interaction was mentioned previously: the opposing viewpoints (and thus objectives) of the operator and the traveller. The transport network determines the quality of the transport services and thus the usage of the network. And if capacity is a concern, the number of travellers using the network, also influences the quality of the services. Travel demand can thus be assumed to be either fixed or dependent on travel quality (usually travel time), while travel quality (travel time) can be assumed to be dependent on the network only or on both the network and the level of demand (Van Nes 2002). If this interaction is however balanced, an appropriate trade-off can be met. That is, if the public transport operator maximises profit (while taking into account that offering inadequate services will reduce patronage and thus revenues), an optimum trade-off between the operator's interests and those of the travellers can be achieved.

2.2.6 THE REALITY OF TODAY'S NETWORKS

The vast and eminent nature of today's networks amplifies their complexity and their large scale application.

Firstly, the networks are experiencing increasing congestion, especially in, but not limited to, the transport- and telecommunication networks. Secondly, alternative behaviours among the transport network users (which can lead to paradoxical phenomena) are manifesting. Moreover, in Dibbelt *et al.* (2012) it is stated that, with the emergence of electric vehicles and their inherent range restrictions, the paradox between using private- and public transport may become even more significant. Thirdly, with the advent of the internet, interactions between the networks themselves can also be observed (Nagurney and Smith 2011). And lastly, real world traversals are increasingly demanding that the different modes of transport be linked extensively. As a result, realistic transit scenarios are tending to involve modal changes on a frequent basis.

Dibbelt *et al.* (2012) state that, in order to keep up with these transport network phenomena, an integrated system, that can handle multiple transport networks, is needed. This gives rise to the multimodal route planning problem in which one is given multiple transport networks (e.g. pedestrian, road, and public transit) and asked to determine a best integrated journey between two points of travel. However, in order to accommodate for such transit scenarios, the appropriate information technologies need to be integrated. As mentioned previously, technology can be used to obtain data, and then, by transforming the data to information that is valued by the traveller, this information can be presented in a manner most suitable to the traveller. Moreover, by creating informed (i.e. intelligent) travellers, people may choose to undergo a voluntarily shift from their strictly dichotomous choice between private vehicle or public transport to multimodal transport.

2.3 MULTIMODAL TRANSPORT

2.3.1 MULTIMODAL TRANSPORT AND THE LAYER MODEL

In Van Nes (2002), a layer model, that provides a framework to analyse a transport system, is developed. The basic model consists of three layers: activities, transport services and traffic services; and two markets between them: the transport market and the traffic market. Refer to Figure 4 (Van Nes 2002).

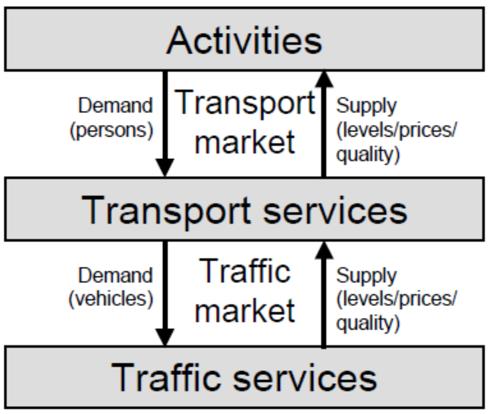

FIGURE 4: LAYER MODEL FOR TRANSPORT SYTEMS

Multimodal transport is related to the second layer: transport services that include private- as well as public transport. That is, multimodal transport implies that more than one transport service is used for making a trip; whether being combinations of private transport- and public transport services, or combinations of public transport services. These transport services are influenced by the vehicle, the network, and all service attributes, and thus determine the quality of the whole trip, i.e. from door-to-door (Van Nes 2002). The door-to-door information logic, imposed by multimodal transport, is not only one of the key benefits of multimodal transport, but it is also seen as a prominent factor in encouraging the use of multimodal transport as it caters for informed (i.e. intelligent) travellers.

2.3.2 UNIMODAL- VERSUS MULTIMODAL TRANSPORT

The concept of multimodal transport is the inverse of unimodal transport.

Van Nes (2002) defines multimodal transport as personal trips consisting of combinations of vehicle- or service modes. Examples are combinations of private- and public transport as well as combinations of functionally different public transport services. The latter could either entail traversing within the same mode of public transport, but between different mode operators (i.e. unimodal transport); or traversing between different modes of public transport.

Figure 5 (Van Nes 2002) is a direct extension of Figure 4 (Van Nes 2002), but with the focus placed on multimodal transport.

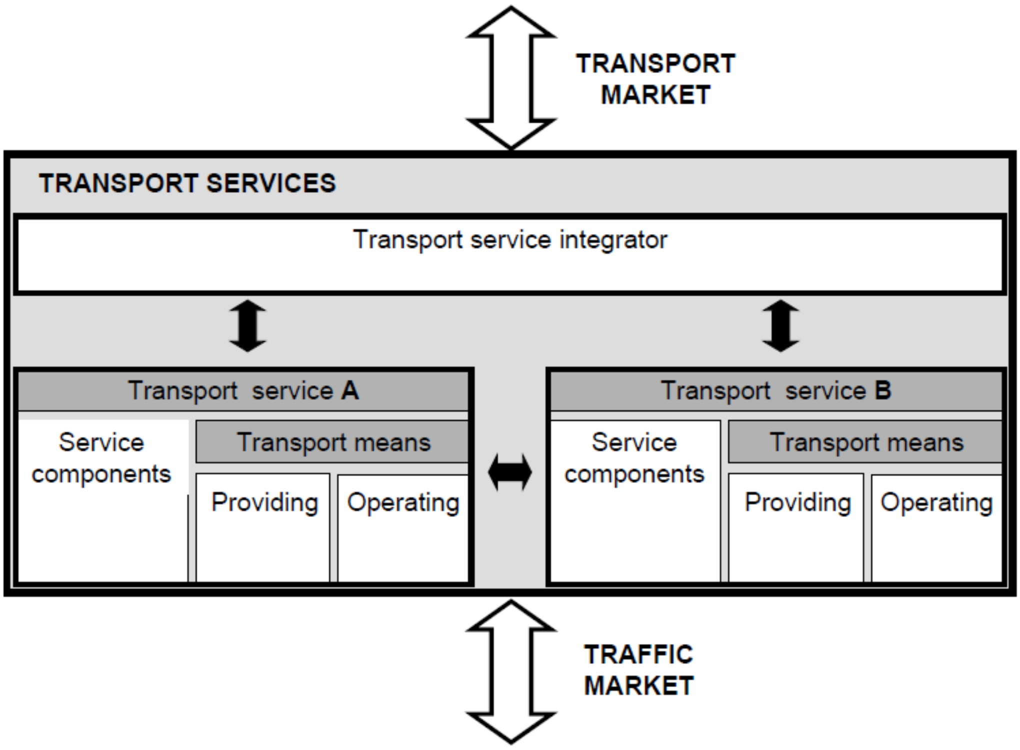

FIGURE 5: MULTIMODAL TRANSPORT AND THE LAYER MODEL

Evidently, travellers traversing in a multimodal transport network undergo frequent modal changes where (inter- and intra-) transferring is required. Therefore, while unimodal transport networks are often designed to minimise the number of transfers, the practicality of multimodal transport always requires and is based on transfers. Furthermore, in contrast to unimodal transfers, multimodal transfers involve switching between different network levels, different modes, and different organisations (Van Nes 2002). The different network levels are discussed in the Section 4.2.1.

2.3.3 BARRIERS IN ACHIEVING MULTIMODAL TRANSPORT

In order for people to voluntarily shift from their strictly dichotomous choice between private vehicle or public transport to multimodal transport, the barriers in multimodal travel situations first need to be considered and rectified. Rehrl *et al.* (2007) identified five main barriers, namely:

1. Lack of public transport information in the private transport environment.

Currently, the digital road networks (as used in car navigation systems) typically ignore public transport. Timetable information, real time information about the status of the public transport network, and information on the availability of free parking lots at Park-and-Ride facilities are only some of the examples of the information that lacks in the private transport environment.

2. The complexity of public transport networks and difficult transfers.

Public transport networks often provide obstacles and are deemed by travellers as complex; mostly due to a feeling of uncertainty or a fear of the unknown. Travellers who are not used to public transport or travellers, who use the public transport network for the first time, seek answers about a number of questions. These questions typically arise before or on entering an unknown public transport network. Furthermore, when it comes to situations where modal change is required, people often get lost. Typical situations of modal change are from car to public transport, from public transport to public transport, or from public transport to Non-Motorised Transport (NMT).

3. Lack of information system integration and personalisation.

Typically, information systems for private- or public transport are heterogeneous and do not span over different vehicle- or service modes. When a traveller leaves his/her private vehicle, he/she is confronted with a broad variety of new information systems including; local guidance systems, orientation plans, (electronic) timetables, and scoreboards for real time information. However, all these information systems are standalone and do not accommodate for personalised trip information. This forces travellers to do their own integration, which accordingly may result in the travellers experiencing feelings of fear or uncertainty, as well as an increased cognitive load.

4. Lack of end-trip information.

When the traveller reaches the final public transport stop/station, the last barrier is to find the precise address. Whereas private vehicle travellers are often navigated exactly to their destination address, public transport- (and multimodal-) travellers exiting a public transport network are left to make their own deductions on how to get from the final stop/station to their desired destination address. Information about the final stop/station, where to find the exit, and how to get oriented in the surrounding area, is needed.

5. Lack of return-trip information.

An additional barrier is the missing (or even non-existing) information regarding the return trip. This includes navigation and guidance back to the public transport stop/station, different route possibilities, and detailed information on the possible sections of the overall route.

2.3.4 JOURNEY MANAGEMENT IN MULTIMODAL TRANSPORT

THE PHASES IN A JOURNEY AND THE TRAVELLERS RELEVANT INFORMATION NEEDS THEREIN

As mentioned previously, a key benefit of multimodal journey planners is the door-to-door information logic. Another prominent benefit is that the travellers are given the opportunity to compare different route alternatives (Rehrl *et al.* 2007). Therefore, Rehrl *et al.* (2007) identified the two main phases in multimodal transport as: the pre-trip phase and the on-trip phase expanded and adjusted with the end-trip information.

Before starting a journey, i.e. the pre-trip phase, travellers determine their key parameters such as travel purpose, time frame, price expectations, or preferred means of transport. The relevant information needed in the pre-trip phase therefore include the required connections, the start and end parts of the transit, transport mode options, number of transfers, public transport schedules, transfer descriptions, prices, and the possibility of map visualisations of the route.

After starting the journey, i.e. the on-trip phase, information about the travel tasks along a selected route is necessary. Travel tasks include multimodal trip planning in private vehicles, searching for Park-and-Ride facilities, navigating to Park-and-Ride facilities, changing from private- to public transport, orientation within public transfer facilities, orientation along public transport routes, and orientation on the last part of the transit, i.e. from the public transport stop/station to the destination point. The latter relates to the end-trip information.

Rehrl *et al.* (2007) define journey management as follows:

> "JOURNEY MANAGEMENT ENCOMPASSES THE FUNCTIONALITY OF STORING PERSONAL ROUTES, ACCESSING THESE PERSONAL ROUTES LATER VIA DIFFERENT INFORMATION SYSTEMS, KEEPING A PERSONAL HISTORY OF PLANNED ROUTES, OR PREFERRED TRAVEL LOCATIONS, AND CENTRALLY STORING ROUTES GENERATED ON DIFFERENT DIGITAL ASSISTANTS LIKE IN-CAR NAVIGATION, WEB-BASED JOURNEY PLANNER, OR MOBILE JOURNEY PLANNER."

THE REQUIREMENTS FOR MULTIMODAL JOURNEY INFORMATION

According Rehrl *et al.* (2007), the four functional requirements for multimodal journey information are:

1. **Personalisation** of the information system. This requires the information provided to be directly related to one person. Personalisation should allow for settings such as: the selection of preferred modes of transport, the exclusion of unwanted modes of transport, the option to set personal walking preferences, to select mobility requirements, to specify a maximum number of transfers, to select time constraints, or to select waypoints[2].

2. **Continuity** of the information system. This implies that the information system is always active and can be used in whatever situation the traveller is in. Continuous on-trip access to multimodal trip data starts with travel planning in the pre-trip phase, nevertheless it is also important to provide travellers with access to trip data along the whole journey, regardless whether a person is travelling by private vehicle, bus, train, or NMT. Furthermore, end-user devices (such as mobile journey planners) that are used along the multimodal route should be equipped with applications that read the trip descriptions and extract the right section of the trip. Therefore making the multimodal trip interoperable, exchangeable, accessible from everywhere, and self-describing.

3. **Mobility** of the information system. This is attained when the information system is accessible throughout the traveller's transit, whether it is mobile journey planners or information terminals at bus stops or train stations.

4. **Seamlessness** is reached when the information system not only provides information for one location or situation, but also informs the traveller independently from his/her

[2] A place or point between major points on a route.

current location. However, services from different domains (e.g. route planning for private vehicles, route planning for public transport, timetable information, parking information, real time traffic data) are typically not interoperable. Hence, provision for some additional interoperability layer, for integrating these services, needs to be made.

It is therefore evident that, in order to encourage more people to take advantage of multimodal transport, new integrated approaches, available on various information service media, accessible from anywhere, and that provide travellers with the appropriate personalised information on private- and public transport systems, need to be deployed.

2.4 REINFORCE TRANSPORT SYSTEM WITH ITS INITIATIVES

2.4.1 INTRODUCTION

As transport networks become more congested and as the need for sustainable mobility (and thus multimodal transport) becomes more apparent, the need to adopt policies that manage demand and make full use of existing resources becomes unmistakable (Vanderschuren 2006). Fortunately, with the advances in information technology, such as Intelligent Transport Systems (ITS), authorities are in the position to meet this need. Neudorff *et al.* (2006) define ITS as follows:

> "ITS IS THE USE OF DIFFERENT TYPES OF ADVANCED TECHNOLOGIES (E.G. ELECTRONICS, COMPUTER, COMMUNICATIONS, AND SENSOR TECHNOLOGIES), IN AN INTEGRATED MANNER, TO INCREASE THE EFFICIENCY AND PRODUCTIVITY OF TRANSPORT SYSTEMS BY IMPROVING USER MOBILITY AND SAFETY."

This author believes that if South Africa advocates an intelligent transport scheme, grounded on ITS applications, the nation will be in the position to more effectively monitor what is going on, to more accurately predict what might happen in the future, and to manage its transport system proactively on an area-wide basis. Furthermore, if the entire transport system (i.e. both the private- and public transport systems) is reinforced with ITS applications, the realisation of a multimodal transport system will be within reach. And, as a result, the deficiencies of the current heterogeneous non-integrated systems can be overcome and the nation thus can focus on optimally utilising its existing resources (i.e. the transport networks).

2.4.2 OVERVIEW OF INTELLIGENT TRANSPORT SYSTEMS

ITS OBJECTIVES

Vanderschuren (2006) identified six main objectives/benefits relating to ITS. These are discussed below.

1. Safety.

Although unwanted, crashes and fatalities are inevitable occurrences in transport networks. Several ITS applications aim to minimise the risk of crash occurrence as well as to lessen the probability of a fatality, should a crash occur.

2. Mobility.

Improving mobility (and reliability) by reducing delay and travel time is a key objective of many ITS components.

3. Efficiency.

Many ITS components seek to optimise the efficiency of existing facilities and use of rights-of-way so that mobility and commerce needs can be met while reducing the need to construct or expand facilities. This is accomplished by increasing the effective capacity[3] of the transport system.

4. Productivity.

The implementation of ITS applications may not only reduce operating costs, but may also allow for productivity improvements. In addition, ITS alternatives may have lower acquisition and life cycle costs compared to the traditional and conventional transport improvement techniques.

5. Energy and Environment.

The air quality and energy impacts of ITS applications are very important considerations, particularly for non-attainment areas[4].

6. Customer Satisfaction.

Given that many ITS projects were specifically developed to serve the public, it is important to ensure that user (i.e. customer) expectations are being met or surpassed.

ITS APPLICATION DESCRIPTION

ERTICO[5], the European equivalent of ITS America[6], divides ITS applications into three groups:

[3] Effective capacity is the maximum potential rate at which persons or vehicles may traverse a link, node or network under a representative composite of roadway conditions including: weather, incidents and variation in traffic demand patterns.

[4] Area that does not meet one or more of the National Ambient Air Quality Standards for the criteria pollutants designated in the Clean Air Act.

[5] www.ertico.com

1. Intelligent Traffic Management Systems measure and analyse traffic flow information and use ITS applications to reduce problems. Examples are computerised traffic signal control, highway and traffic flow management systems, electronic licensing, Incident Management Systems (IMS), electronic toll and pricing, traffic enforcement systems and intelligent speed adaptation.
2. Intelligent Passenger Information Systems improve the knowledge base of the traveller. Examples are passenger information systems, in-vehicle route guidance systems, parking availability guidance systems, digital map database and variable messaging systems.
3. Intelligent Public Transport Systems include ITS measures that aim to improve public transport performance. Examples are intelligent vehicles, intelligent speed adaptation, transit fleet management systems, transit passenger information systems, electronic payment systems, electronic licensing, transportation demand management systems and public transport priority.

If one however solely focuses on the direct impact of ITS applications, and the associated economic benefits thereof, only the safety, mobility, efficiency and customer satisfaction objectives need to be considered. Energy and environmental benefits generally focus on benefits with regards to natural resources and are thus secondary effects. And as mentioned previously, the implementation of ITS applications can possibly reduce operating costs and are also likely to allow for productivity improvements.

Refer to Table 1 (Vanderschuren 2006) for an overview of ITS applications, per objective, according to the three groups distinguished by ERTICO.

[6] www.itsa.org

TABLE 1: OVERVIEW OF ITS APPLICATIONS PER OBJECTIVE

	Intelligent Traffic Management Systems	**Intelligent Passenger Information Systems**	**Intelligent Public Transport Systems**
Safety (Aim to reduce accidents and dangerous situations.)	• Variable speed limits • Lane management • Incident management • **Warning systems** • **CCTV cameras** • Automatic vehicle identification • Intelligent speed adaptation • Weight in motion	• Navigation systems • Parking guidance • Cruise control • **Warning systems** • Intelligent speed adaptation • Black-box systems • Automated vehicle identification • Docking systems • Distance warning	• Fleet management • **Navigation systems** • **Electronic ticketing** • CCTV cameras • High-speed ground transport • Automatic vehicle identification • Intelligent Speed adaptation • Distance warning • GPS tracking
Mobility and Efficiency (Aim to optimise the use of road capacity, and reduce unnecessary and inefficient driving.)	• Variable speed limits • Lane management • Incident management • **Warning systems** • **CCTV cameras** • Ramp metering • Traffic control • Electronic toll collection • **Real time information** • Parking guidance	• Navigation systems • Parking guidance • Cruise control • **Warning systems**	• Public transport priority • Fleet management • **Navigation systems** • **Electronic ticketing** • **System integration** • High-speed ground transportation • **Real time information**
Customer Satisfaction (The provision of information, security etc.)	• **CCTV cameras** • Lane management • **Warning systems** • Electronic toll collection • **Real time information** • Parking guidance	• Navigation systems • Parking guidance • **Real time information** • Electronic toll collection • Docking systems • **Warning systems**	• **Real time information** • **System integration** • **Electronic ticketing** • CCTV cameras

ITS APPLICATIONS RELATED TO MULTIMODAL TRANSPORT

The ITS applications, that are deemed necessary for this research project, are the ones in bold in Table 1 (Vanderschuren 2006). An explanation of each follows.

Warning systems: CCTV cameras and VMS with real time information.

The general aim of warning systems is to promote and enable seamless traffic flow by creating informed travellers. Closed Circuit Television (CCTV) cameras are used to capture live video footage of traffic flow among major roads in a road network. This CCTV footage is managed 24/7 by a Transport Management Centre (TMC) in order detect and be aware of events such as excessive fog, congestion, and incidents. When such an event is detected, the car drivers are promptly informed via Variable Message Signs (VMS). On these warning signs they might, for instance, be advised to drive slower or be notified that congestion should be expected (Vanderschuren 2006).

Navigation systems with real time information.

With regard to public transport, real time information can be used as a Travel Demand Management (TDM) tool. TDM aims to find ways to influence human behaviour and thus encourage a shift from private- to public transport (Vanderschuren 2006). ITS applications such as Advanced Traveller Information Systems (ATIS) can be used to enhance the attractiveness of public transport, over that of the private car, by providing travellers with information such as: expected travel time, expected waiting time at stops/stations, and navigational information (i.e. how to reach stops/stations and destination points, recommended routes to take, etc.).

Electronic ticketing.

Electronic ticketing removes the need to carry exact cash and thus allows for public transport payments to be made quicker and easier. This in turn might improve the efficiency of the public transport system. Furthermore, electronic ticketing also allows for the tracking of a user's ID. The public transport environment might then, as a result, be safer because it will be more difficult for criminals to remain anonymous. Moreover, electronic ticketing can also aid TDM by providing opportunities to improve the collection of travel demand data. And lastly, Vanderschuren (2006) states that, if an electronic ticketing system - with the appropriate multimodal structure for Automated Fare Collection (AFC) - is in place, it may also allow for optimum system integration.

2.4.3 THE PRIVATE TRANSPORT PHENOMENA AND THE COUNTERACTING ITS APPLICATIONS

In the private transport environment, drivers are increasingly demanding a safe, reliable, and predictable trip. This refers to a trip that is safe from physical harm, provides a consistent service, and is predictable (within an acceptable variance) in terms of travel time. These considerations also apply to emergency and incident management agencies, and to the drivers who are affected by the incident (Neudorff *et al.* 2006). Essentially, drivers expect mobility, accessibility and reliability as a given.

If Advanced Traffic Management Systems (ATMS) (i.e. Freeway Management Systems (FMS), Arterial Management Systems (AMS) and Urban Traffic Control (UTC)) are however exploited, these rising expectations can be met. Examples of ITS applications used in ATMS are: surveillance systems such as Closed Circuit Television (CCTV) cameras, communication systems such as Variable Message Signs (VMS), adaptive traffic signal control, traffic detectors and a Highway Advisory Radio (HAR).

According to Neudorff *et al.* (2006), if drivers are informed about roadway performance and the extent and duration of congestion, their attitude towards the road network is seen to improve. This information gives them carte blanche to make decisions that give them the perception of having more 'control over their lives'.

2.4.4 THE PUBLIC TRANSPORT PHENOMENA AND THE COUNTERACTING ITS APPLICATIONS

One of the main obstacles with effectively operating and managing the nation's public transport system is that people are reluctant to change. The process of encouraging car drivers to undergo a voluntary modal shift from private- to public transport, is and will be a potentially long and complex one (Russell 2011).

There are several challenges that the public transport environment faces in mitigating the effects of the car trend. Firstly, driving a car is popular because it fits a need for individualisation, a need for freedom and privacy, and a need for power and control. Secondly, a traveller's mode choice is often habitual rather than rational. Habitual travellers may not consider options other than their habitual travel mode, even when the other options may be more favourable in terms of travel time, travel costs and environmental costs. As a result, travellers with the habit of travelling by car may not consider the possibility of travelling by public transport. Lastly, in general, most travellers' intention to use public transport is relatively low. Travellers are afraid they lack control while travelling by public transport and hence experience a public transport trip as nerve-racking (Dziekan and Dicke-Ogenia 2010).

If South Africa however exploits Advanced Public Transport Systems (APTS) (i.e. Automated Fare Collection (AFC), Interoperable Fare Management (IFM) and Advanced Traveller Information Systems (ATIS)), citizens may be encouraged to use public transport, within a multimodal platform, as their preferable means of transport.

With the aid of AFC, the travellers' payment method is simplified due to the provision of electronic fare payment. AFC thus facilitates fare integration. And if AFC is properly exploited, an IFM structure can be attained. That is, the traveller is provided with a single fare card that can be used on several modes of transport, operated by several independent transport operators, and in several locations. The goal of AFC and IFM are thus to make public transport more convenient for the travellers. ATIS, on the other hand, are based on information provision. That is, to provide travel time and trip planning information to the travellers. The goal of ATIS is thus to create intelligent (i.e. informed) travellers.

APTS thus help to make public transport a more attractive option for the travellers since it provides them with enhanced visibility into the arrival- and departure status (and overall timeliness) of buses and trains (Ezell 2010). If the citizens are provided with a convenient, reliable and safe public transport system, while being informed about their travel options, the stigma against public transport may diminish and public transport may become a more preferable transit choice.

2.4.5 CHALLENGES IN IMPLEMENTING ITS

In Ezell (2010), the following challenges are underlined.

Firstly, the vast majorities of ITS applications are subject to system interdependency challenges; require system coordination to deploy, and at the same time, the adoption by the individual users; and should operate at scale to be effective. Secondly, the uncertain marketplaces for ITS applications (due to the higher risk associated with new systems) impede its development. Thirdly, ITS face a range of institutional barriers, and these organisational challenges determine how the performing organisations, often across jurisdictions, establish and maintain common plans and schedules; how they allocate funding priorities; and how information is shared. Other ITS challenges include the lack of expertise within local and regional transport agencies with regard to the technologies underlying ITS applications and the implementation thereof. And lastly, the lack of technical standards for ITS technologies inhibits the integration of ITS applications pursued by different organisations.

As for South Africa, no common ITS architecture and thus no common technical standard, for the technologies underlying ITS applications, exist. However, this author believes that, with the realisation of an integrated multimodal transport system, institution integration may be encouraged. As a result, the development of a common ITS architecture may follow, and thus the meeting of the challenges mentioned, will be possible.

2.5 THE PROMOTION OF A CENTRALISED TRANSPORT DATABASE

2.5.1 INTRODUCTION

Elmasri and Navathe (2011) state that database systems[7] are becoming an increasingly essential component of life in modern society. Most people, without maybe being aware thereof, encounter several activities, on an everyday basis, that involve some interaction with a database (DB). For example, if one goes to the bank to deposit or withdraw funds, if one makes a reservation (e.g. hotel or airline) online, or if one purchases an item (e.g. a book) online, the chance of these activities involving someone or some computer program accessing a DB is very good. Moreover, in the past few years, advances in technology have led to exciting new applications of database systems and databases.

This author believes that, these emerging and evolving technologies foster the proposition made herein. That is, the promotion of multimodal transport. However, as mentioned previously, in order to encourage more people to take advantage of multimodal transport, new integrated approaches, available on various information service media, accessible from anywhere, and that provide travellers with the appropriate personalised information on private- and public transport systems, need to be deployed. As a result, the development of a centralised database, which acts as a data hub repository for all modes of transport, is required.

2.5.2 WHY PROMOTE A DATABASE?

A DB is not just a collection of files, but rather a central source of related data[8] meant to be shared by many users, for a variety of applications (Kendall and Kendall 2008).

A DB derives its data from some source, has some degree of interaction with events in the real world, and has an audience that is actively interested in its contents. Moreover, a DB can be of any size and complexity, and it may be generated and maintained manually or it may be computerised (Elmasri and Navathe 2011). The advantages of storing data in a DB versus that of a conventional file system are identified by Kendall and Kendall (2008) to be the following:

- Due to the fact that data stored in a DB is meant to be shared by many users, it is of cardinal importance that data is stored <u>only once</u>. This criterion ensures the integrity of the data, i.e. data that is both accurate and consistent.

[7] A database, with the appropriate Database Management System (DBMS) software in place, forms a database system.
[8] Known facts that can be recorded and that have implicit meaning.

- When a user requires particular information, a well-designed DB anticipates the need for such information. Consequently, the data stored in a DB has a higher probability of being available in comparison to that of a conventional file system.
- A well-designed DB can also be more flexible than separate files since it can adapt and evolve as the needs of users and applications change.
- By using the DB approach, users have the advantage of constructing their own view of the data, without them having to be concerned with the actual structure of the DB or its physical storage.

2.5.3 THE IMPLICATIONS OF USING A DATABASE APPROACH

The database (DB) approach has the following five implications (Elmasri and Navathe 2011):

1. Potential for enforcing standards.

The DB approach permits the Database Administrator (DBA) to define and enforce standards among DB users, irrespective of their various institutions. Standards can be, among others, defined for names and formats of data elements, display formats, report structures, and terminology. With the DB approach, the DBA can thus more easily enforce standards in a centralised database environment; thereby facilitating the communication and cooperation among users from various institutions.

2. Reduced application development time.

Designing and implementing a large multi-user DB from scratch may take more time than writing a single specialised file application. However, once a DB is up and running, substantially less time is generally required to create new applications by using database management software. As stated in Elmasri and Navathe (2011), the development time of a new application using a Database Management System (DBMS) is estimated to be one-sixth to one-fourth of that for a conventional file system.

3. Increased flexibility.

With the passing of time, it may be necessary to change or update the structure of a DB as the requirements change. By implementing a DB approach together with modern database management software, certain types of evolutionary changes to the structure of the DB (without affecting the stored data and the existing application programs) are possible.

4. Availability of up-to-date information.

The DB, with the appropriate DBMS in place, allows for the DB to be made available to all users. Moreover, as soon as one user's update is applied to the DB, this update is immediately revealed to all the other users. This availability of up-to-date information is made possible by the concurrency control and recovery subsystems of a DBMS, and is an essential feature for many transaction-processing applications (i.e. OLTP – discussed in Section 4.9.2).

5. Economies of scale.

The DB approach permits consolidation of data and applications; thus reducing the number of wasteful overlap between activities of data-processing personnel from different institutions, as well as reducing any redundancies among applications. As a result, the institutions can (by working together) reduce their overall costs of operation and management by investing in more powerful processors, storage devices, or communication equipment, rather than each having to purchase its own (probably lower performance) equipment.

2.5.4 THE IMPLICATIONS OF IMPLEMENTING A CENTRALISED DATABASE

If a centralised DB exists, the integration of Intelligent Transport Systems (ITS) and thus information sharing across all modes of private- and public land transport, for internal and external use, will be possible. Therefore, even though people may be reluctant to change, the utilisation of personalised Advanced Traveller Information System (ATIS) will meet people's inclination to acquire more information. Consequently, people's perception of multimodal transport may be influenced for the better and traversing in an integrated manner may become the norm.

2.6 JOURNEY PLANNER: INFORMED TRAVELLERS

2.6.1 INTRODUCTION

Journey planning constitutes a common decision faced by many travellers. According to Zografos *et al.* (2010), if comprehensive- and accurate information for journey planning is made available to the travellers, it can: stimulate knowledge and confidence, foster positive attitudes towards the service provider and create favourable perceptions of efficiency and security. Furthermore, with information becoming such a vital commodity in everyday life, it can be argued that informed travellers are the key to successful future transport services.

Nowadays, with the deployment of the internet and wireless information- and communication technologies, the development of web-based Journey Planners (JPs) that facilitate travellers with planning their travel decisions anytime and anywhere, has been stimulated (Zografos *et al.* 2010). Most of the existing web-based JPs provide alternative travel plans, either for urban- or interurban trips, but with limited geographical scope (local or regional) and applicable only to international unimodal trips.

In Zografos *et al.* (2010), examples of JPs provided by five European countries, China and Japan, are given. These are listed below.

- **Italy**: Busbussola - Public Transport JP of ATAF Spa, (www.ataf.net); Timetables search engine - Public Transport JP of Autolinee F.lli Lazzi Spa, (www.lazzi.it/eng/activenews.asp); Google Transit Firenze, (www.google.com/transit); "Mobiliter" - Emilia Romagna, (www.mobiliter.eu).
- **United Kingdom**: Megabus, (www.megabus.com); The Trainline, (www.thetrainline.com); Transport Direct (www.transportdirect.info); Traveline Scotland, (www.travelinescotland.com).
- **Finland**: Helsinki Metropolitan Area Council (YTV), (www.ytv.fi/eng); Tampere City Transport, (http://atlas.tripplanner.fi/tkl/en); Oulu Region Public Transport Journey Planner, (www.linjakas.fi/lang/ en); Linjakas, Journey.fi route planner, (www.journey.fi).
- **Germany**: The Intermodal Journey Planner (IJP) by Mentz DV Munich.
- **Denmark**: Rejseplanen.dk, (www.rejseplane.dk).
- **Greece**: ENOSIS Urban Journey Planner, Greek City Journey Planners, e.g. Larisa, (http://larisa.gnomon.com.gr); Myroute Journey Planner, (www.myroute.gr).
- **The Netherlands**: NS treinplanner, (www.ns.nl); Schiphol VluchtReisplanner.jsp, (http://schiphol.nl/_van_naar_schiphol); 9292ov Reisplanner, (http://routeplanner.9292ov.nl).
- **Spain**: Guia Campsa, (www.guiacampsa.com); Community of Madrid, (www.ctm-madrid.es).
- **China**: Hangzhou Bus, (www.hzbus.com.cn/index.jsp); Hangzhou Transport, (www.hzcb.gov.cn).
- **Japan**: Yahoo, Route Selection, (http://transit.yahoo.co.jp).

2.6.2 MULTIMODAL ITINERARY PLANNING

ITINERARY, JOURNEY, TRIP, JOURNEY SEGMENT AND LEG

An itinerary stipulates how a journey is to be carried out by considering possible routes and time schedules as well as the means of traversing one or more journey segments. A journey is defined as the total distance to be travelled. A trip forms the part of the journey accomplished by means of one transport mode, according to a planned route and time schedule. A trip may also consist of one or more legs, and include stops at two or more transfer nodes. A leg is the part of a trip that is between two consecutive stops/stations at transfer nodes. A journey segment constitutes a part of a journey that may be carried out by means of one or more legs of one or more trips, and may consist of a set of consecutive journey segments executed by different transport modes (Natvig *et al*. 2009). A visual depiction of these definitions can be seen in Figure 6 (Natvig *et al.* 2009).

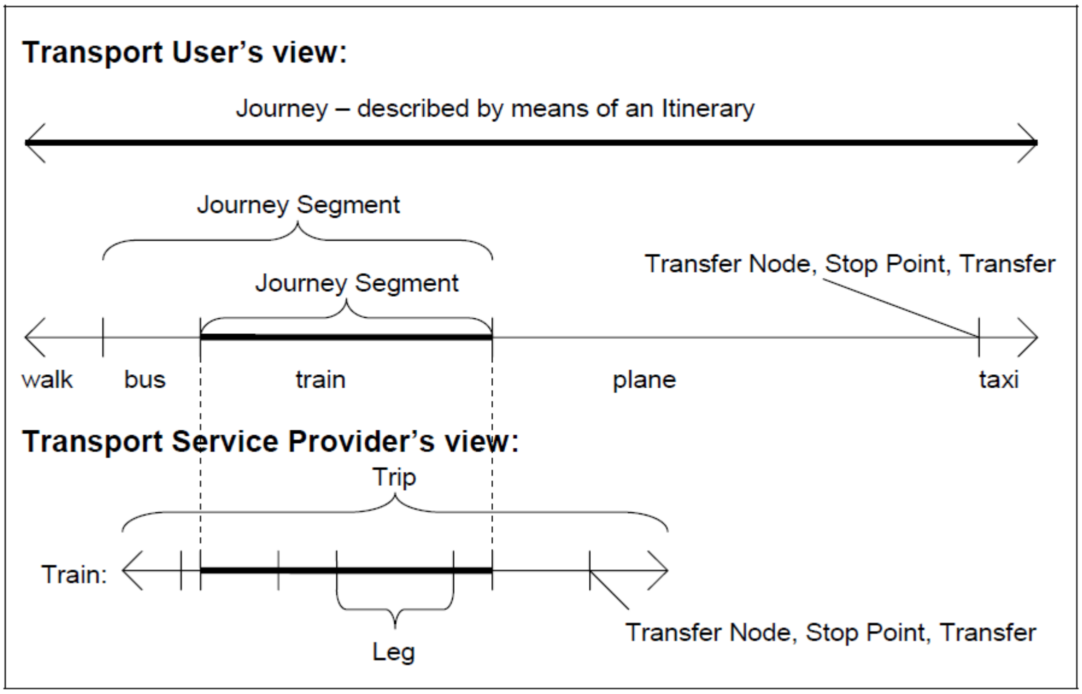

FIGURE 6: MULTIMODAL ITINERARY PLANNING CONCEPTS

As can be seen in Figure 6 (Natvig *et al.* 2009), the transport service provider (of a certain mode of transport) is responsible for providing an itinerary that specifies how the user can traverse by using its mode of transport. If the transport user however wants to traverse using different modes of transport, with a non-integrated system in place, he/she has to combine information from several itineraries, received from different transport service providers, in order to obtain an applicable itinerary that encompasses his/her whole transport journey. As mentioned previously, this may result in the transport users experiencing feelings of fear or uncertainty, as well as an increased cognitive load.

A GENERALISED-COST APPROACH FOR JOURNEY PLANNING

Most of the existing JPs found, use either the direct cost incurred during transit or the travel time as the parameter to find the optimum path for making a journey. In these models, the assumption that the travellers' objectives are simply to minimise their travel costs, when in fact they might attach greater significance to time saving or vice versa, can thus lead to errors in itinerary planning.

According to Kasturia and Verma (2010), it is generally a natural tendency for public transport users to attach differential importance to various segments of a journey: e.g. walking, waiting time, and travel time. For example, a person might perceive waiting time at terminals as uncomfortable and would thus attach higher preference to a route in which the waiting time is a minimum. Likewise, an elderly or disabled person might not like to walk more than a certain distance to reach a stop/station and would thus prefer a route that has minimum walking time. Moreover, some users might prefer direct routes as compared to routes involving numerous transfers.

Kasturia and Verma (2010) further state that these types of considerations are especially of importance in developing countries where the various modes of public transport are generally not integrated properly, and where the transfer time from one mode to another may thus, as a result, be very long. Furthermore, in developing countries, a major share of public transport users are commonly captive riders, for whom the fare paid for making a trip is also an important criterion in choosing his/her most suitable transit route. As a result, Kasturia and Verma (2010) developed a Generalised–Cost (GC) approach: one in which all the elements considered in a traveller's itinerary planning are included in finding the optimum route, at differential importance, given by the traveller concerned in making the choices. With this approach, the basic idea is thus to mimic the differential importance given by the public transport user to the various legs of a journey, while selecting the best route for travelling between an Origin-Destination (OD) pair in a multimodal transport network. Refer to Figure 7 (Kasturia and Verma 2010).

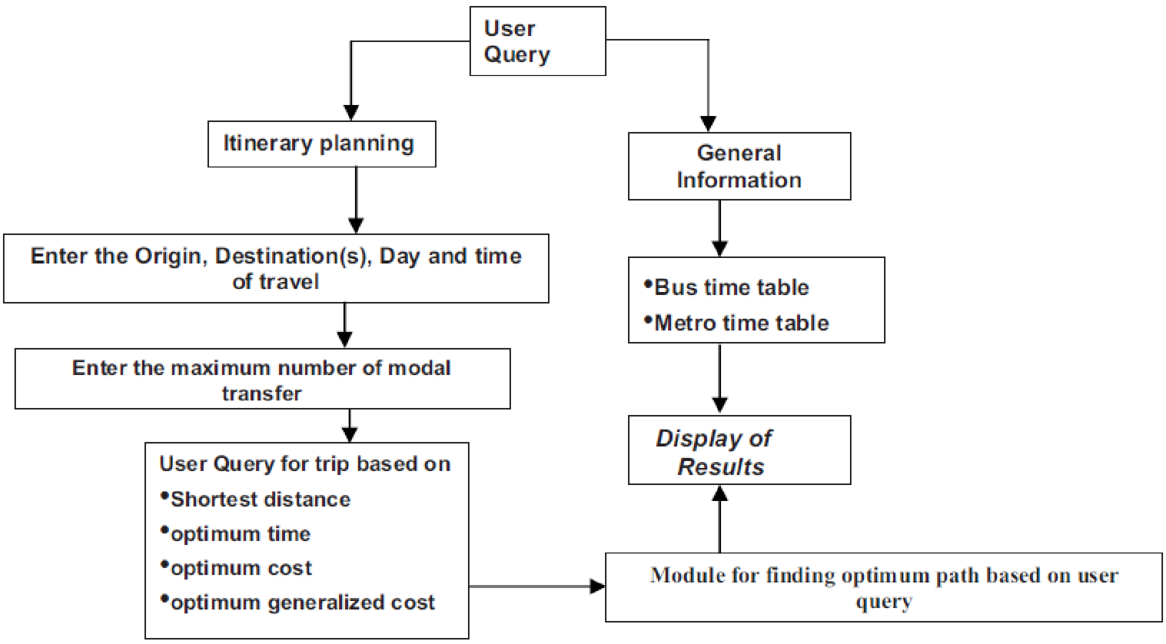

FIGURE 7: THE USER'S OPTIONS

With the user interface proposed in Figure 7 (Kasturia and Verma 2010), a traveller may either query for general information on routes and schedules or he/she may choose the option of itinerary planning. If the traveller chooses the latter, he/she is required to provide input on the journey origin, the destination, the travel date, and the travel time. After providing this information, the traveller is prompted to provide the maximum number of transfers that he/she wishes to undergo. And then, lastly, the traveller is prompted to provide the criterion for which the best route is to be calculated. The criteria, from which the traveller may choose, are as follows:

- Minimum GC.
- Minimum time.
- Minimum cost.
- Shortest distance.

If the traveller chooses the GC option, he/she will be further prompted to give weights (regarding the importance they wish to attach) to each leg in the journey, whereas with the other options, no additional information needs to be provided.

This GC approach presented in Kasturia and Verma (2010) has been implemented in the commercially available Geographical Information System (GIS) software TransCAD by using its associated programming language GISDK. According to Kasturia and Verma (2010), TransCAD was chosen because it has been designed specifically for the use by transport professionals to store, display, manage, and analyse transport related data; it combines GIS and transport modelling capabilities into a single integrated platform; and it provides application modules for routing, travel demand forecasting, and public transit.

2.6.3 PERSONALISED INTELLIGENT TRANSPORT SYSTEMS

As mentioned previously, public transport networks are difficult to use when the user is unfamiliar with the area he/she is travelling to. According to Aguiar *et al.* (2011), this is true for both infrequent users (including visitors) and regular users who need to travel to unfamiliar areas. In these situations, adequate information on journey navigation can considerably ease the use of public transport and can thus be seen as the driving factor in motivating travellers to prefer certain modes over other modes of transport (Aguiar *et al.* 2011).

As a result, interactive maps, route planners, and real time service alerts have become essential components in public transport systems (Lathia *et al*. 2010). However, it is clear from the associated JP-research that have been conducted, that most of these systems notably lack the ability to dynamically tailor information to the individual needs of each traveller. According to

Lathia *et al*. (2010), mining each user's travel history, by utilising information obtained from automated ticketing systems, has the potential to address this gap.

MINING PUBLIC TRANSPORT USAGE WITH AID OF AFC

Personalisation (e.g. the provision of personalised trip time estimates and relevant notifications) offers a rich opportunity to match information to the appropriate individual traveller and thus reduces the traveller's need to manually search for the relevant transit notifications. Lathia *et al*. (2010) state that, in the past, a significant obstacle to personalising public transport information has been the lack of data about individual traveller preferences and -routines. However, according to Lathia *et al*. (2010), with the introduction and widespread implementation of Automated Fare Collection (AFC) systems, a potential channel to this missing data is possible.

According to Aguiar *et al.* (2011), electronic ticketing systems in public transport networks have been, among others, deployed in: Shanghai, London, Helsinki, Istanbul, Moscow, Lisbon, Porto, and they all relish good acceptance among the transport users.

If electronic ticketing is implemented in the form of RFID-based smart cards, a digital record (every time a trip is made) is created. This record can then, by using the RFID technology and the smart card data structure, be linked back to the individual traveller. Lathia *et al*. (2010) state that by mining the travel data that is created as the travellers enter and exit stops/stations, one can obtain immense insight into the travellers themselves. That is, insight into their implicit preferences, travel time behaviours, and commuting habits.

Lathia *et al*. (2010) indicate how AFC systems can be used to reveal individual differences in travel patterns that, in turn, can be used to enable personalised transit services. The two facets of personalisation considered are:

1. Predicting personalised travel times between any origin and destination pair in order to be able to provide users with accurate estimates of their transit times.
2. Predicting and ranking the interest that travellers will have for alert notifications about particular stops/stations based on their past travel histories.

Lathia *et al*. (2010) met these two aspects of personalisation by analysing the travellers' aggregate temporal usage patterns and by determining the underlying differences that exist in individual traveller patterns.

The primary focus of the aggregate behaviour was to highlight systemic patterns that 1) give a broad perspective of the usage of the system and that 2) may impact the ability to accurately predict traveller's travel times or the stops/stations of interest to him/her. And in order to determine travellers' characteristics, the user-centric patterns of travel were highlighted by analysing the repeat trips over time, the usage similarities between different groups of users and the relative travel times (Lathia *et al*. 2010).

The potential opportunities that AFC datasets provide for personalisation services were analysed for the London underground system. The main conclusion drawn from the research conducted in Lathia *et al*. (2010) is that there are a variety of benefits and uses for incorporating data about system users with Intelligent Transport Systems (ITS). Furthermore, it was established that the effectiveness of such a personalised transport system tends to improve over time as the travellers continue to use the system, with significant attitude improvement from the travellers that emerge from using this data.

USING AFC AND RFID AS A MEANS TO PROVIDE TRANSPORT USERS WITH A PERSONAL DIGITAL ASSISTANT

RFID is commonly used for location and tracking of goods in supply chains, as well as indoor positioning, and has previously been proposed for improving the accuracy of Global Positioning System (GPS) positioning by spreading RFID tags in a city. In Aguiar *et al.* (2011), the concept of the latter was expanded to include the usage of electronic ticketing systems for positioning purposes within a transport environment.

The Personal Digital Assistant (PDA) developed in Aguiar *et al.* (2011), utilises the available existing geographically widespread networks of RFID readers to deploy location-based (i.e. positioning) services. And since this proposition of using RFID tags with an electronic ticketing system is independent of the wealth of the passengers, it can thus be used by all. This approach differentiates the proposed PDA from most of the journey planners and navigation assistants currently available.

This proposed PDA, called Navi, does not provide generalised positioning, but rather positioning within the context of a public transport network. In addition, Navi also provides for personalised information about the user's chosen route and not generic information about the public transport network or nearby stops/stations. Furthermore, since Navi is envisioned as an enhanced service that increases the added value of the electronic ticketing infrastructure, is easy and cost efficient to deploy (Aguiar *et al.* 2011).

It is stated in Aguiar *et al.* (2011) that, by pursuing this initiative, the deployment of electronic ticketing will not only improve operations, but can be leveraged upon to enhance user experience. With an enhanced user experience, modal change from private transport can be motivated; the adoption of multimodal public transport network services can be eased, and at the same time, the number of public transport travellers can be increased; and the quality and standard of life in cities can be improved.

2.7 THE MAIN CONSIDERATIONS DRAWN FROM THE RESEARCH

2.7.1 THE PROPOSITION'S ASSOCIATED BENEFITS

The associated benefits, of the portraying aspects needed in attaining a balanced and integrated sustainable transport system, are discussed in the following subsections.

THE BENEFITS OF A MULTIMODAL TRANSPORT SYSTEM

According to Van Nes (2002), if multimodal transport is promoted, the transport system could undergo the following six improvements:

1. Transfers could become more comfortable due to the better design of transfer points required by multimodal transport.
2. The accessibility of public transport services for private modes could be improved, especially in rural areas that have low densities.
3. The public transport services could be better synchronised and coordinated due to the interoperability imposed by multimodal transport.
4. The availability of transport modes at the destination end could be improved by, for instance, combining the multimodal concept with rental services, especially for areas that have a low quality of public transport services.
5. Information could be more easily available, before, during and at the end of the trip. Thus making it easier to plan and complete multimodal trips. Furthermore, the door-to-door information logic, assisted through multimodal transport, could create informed (i.e. intelligent) travellers.
6. The financial aspects of public transport could be simplified, either by integrating a traveller's trip with electronic payment options or by promoting transport service integrators.

THE BENEFITS OF AN INTELLIGENT TRANSPORT SCHEME

It is stated in Ezell (2010) that, if information technology is adequately applied to a country's transport network, five key classes of benefits may follow.

1. An increase in driver- and pedestrian safety.

Intelligent Transport Systems (ITS) can deliver important safety benefits. A wide range of ITS-based applications - from real time traffic alerts, to cooperative intersection collision avoidance, to on-vehicle systems such as anti-lock braking, lane departure, collision avoidance, and crash notification systems - have safety as a principle focus.

2. An improvement in the operational performance of the transport network, particularly by reducing congestion.

ITS can improve the performance of a country's transport network by maximising the capacity of its existing infrastructure, and thus reducing the need to build additional roadway capacity. Maximising capacity is crucial, because, in almost all countries, the increase in vehicle kilometres travelled dramatically outstrips the increase in roadway capacity. Furthermore, in many countries there is either little more room to build, little political will to build, or both.

As an example, ramp metering can increase vehicle throughput (the number of cars that pass through a road lane) from 8% to 22% and increase speeds on roads from 8% to 60% (Ezell 2010).

3. An enhancement in personal mobility and convenience.

ITS enhance driver mobility and convenience by 1) decreasing congestion and maximising the operational efficiency of the transport system and 2) providing drivers and mass transit users with real time traveller information, enhanced route selection and navigation capability. These services help travellers identify and take the most efficient, trouble-free routes and help prevent them from getting lost.

4. The delivering of environmental benefits.

ITS are positioned to deliver environmental benefits by reducing congestion, by enabling traffic to flow more smoothly, by educating drivers on how to drive most efficiently, and by reducing the need to build additional roadways through maximising the capacity of existing ones.

For example, traffic signal light optimisation can improve traffic flow significantly, reducing stops by as much as 40%, cutting gas consumption by 10%, cutting emissions by 22%, and reducing travel time by 25%. Additionally, if real time traffic data is utilised, it could improve traffic signal efficiency by 10%, saving 1.1 million gallons of gas a day nationally and cutting daily carbon dioxide emissions by 9 600 tons (Ezell 2010).

5. A boost in productivity and an expansion in economic and employment growth.

ITS boost productivity and expand economic- and employment growth. By improving the performance of a nation's transport system, thus ensuring that people and products reach their desired destinations as quickly and efficiently as possible, ITS can enhance the productivity of a nation's workers and businesses and boost a nation's economic competitiveness.

THE BENEFITS OF AN IFM STRUCTURE

The benefits, subdivided for authorities, operators and travellers, obtained by implementing an electronic fare media system with the appropriate Interoperable Fare Management (IFM) structure in place, can be seen in Table 2 (Mezghani 2008).

TABLE 2: THE BENEFITS OF IFM

For Authorities	For Operators	For Travellers
• Creation of seamless journeys in public transport networks • Unification of ticketing • Source of new marketing data • Better control of revenues and subsidies • Possibility of extending the scheme to other role players (e.g. taxis) • Projects with political connection value • Improve public transport image • Reduce cost of selling tickets	• Gain new customers with modern approach • Increase medium term operating profit and reduce fraud • Reduce the use of cash • Reduce cost of selling tickets • Reduce maintenance costs • Improve cash flow • Reduction in boarding time • Valuable opportunities to add 'new services' • Source of marketing data for public transport management	• Convenience and speed (no cash required) • Seamless journeys in multimodal, multi-public-transport-schemes • Easy to reload value or renew passes • Easy to obtain new card when it has been lost or stolen • Possibility of additional appreciated services

THE BENEFITS OF A DATABASE APPROACH WITH A DBMS

According to Elmasri and Navathe (2011), the usage of a Database Management System (DBMS) allows for the following nine advantages:

1. Controlling redundancy.

In traditional software development utilising file processing, every user group maintained its own files for handling its data-processing application. As a result, data was often duplicated. However, with the database approach and with the proper DBMS in place, the views of different user groups are integrated during database (DB) design with aid of data normalisation. Data normalisation ensures data integrity (i.e. accurate and consistent data) and saves storage space.

2. Restricting unauthorised access.

When multiple users share a DB, the authorised access to the data needs to be controlled. For example, some users may only be allowed to retrieve data, whereas others may be allowed to retrieve and update data. A DBMS controls the type of access operation (i.e. the retrieval or update of data). Typically, users or user groups are given account numbers protected by passwords, which is used to control the type of access operation permitted.

3. Providing persistent storage for program objects.

Databases can be used to provide persistent storage for program objects and data structures. This is one of the main reasons for object-oriented database systems in which complex objects are stored permanently in an object-oriented DBMS. Therefore, objects that survive the termination of program execution (and can hence be retrieved at a later stage) can be created.

4. Providing storage structures and search techniques for efficient query processing.

Database systems provide capabilities necessary for efficiently executing queries and updates. The DBMS provides for specialised data structures and search techniques to speed up the disk search (a DB is typically stored on disk) for the desired records. This is achieved by using auxiliary files: i.e. indexes[9]. Furthermore, in order to process the database records required for the execution of a particular query, those records need be copied from the disk to the main memory. Therefore, the DBMS often has a buffering or caching module that retains parts of the database in main memory buffers in order to allow for fast query execution.

5. Providing backup and recovery.

A DBMS provides facilities for recovering from hardware- or software failures.

6. Providing multiple user interfaces.

Due to the fact that many types of users with varying levels of technical knowledge (e.g. engineers, business analysts, programmers, etc.) use a database, a DBMS has the ability to support a variety of user interfaces.

7. Representing complex relationships among data.

A DB may include numerous varieties of data that are interrelated in many ways. A DBMS attend to this by having the capability to represent a variety of complex relationships among the data, to define new relationships as they arise, and to retrieve and update related data easily and efficiently.

[9] A data index is a data structure that improves the speed of data retrieval operations on a database table at the cost of slower writes and increased storage space. Indices can be created using one or more columns of a database table, providing the basis for both rapid random lookups and efficient access of ordered records.

8. Enforcing integrity constraints.

Many database applications have certain integrity constraints to which the data needs to comply. The simplest type of integrity constraint involves specifying a data type (e.g. string, integer, character, etc.) for each data item. A more complex type of constraint (that frequently occurs) involves the specification that a record in one file must be related to record(s) in other files. Another type of constraint involves specifying the uniqueness on data item values. A DBMS provide the capabilities for defining and enforcing these constraints.

9. Permitting inferencing and actions using rules.

Some database systems have the capability of defining deduction rules, which when compiled and maintained by the DBMS, causes new information to be inferenced from the stored DB facts. Furthermore, it is also possible to associate triggers with tables. A database trigger is a procedural code, enforcing rules, that is, automatically executed in response to certain events on a particular table or view in a database. A more elaborate method used to enforce rules, is that of a Stored Procedure (SP). When a SP is created, it becomes a part of the overall database definition and its content is invoked appropriately when certain conditions are met.

THE BENEFITS OF A MULTIMODAL ATIS: JP

Advanced Traveller Information Systems (ATIS) have demonstrated benefits in several areas including travel time, consumer satisfaction, system throughput, on-time performance, and environmental impacts (FHWA 1998). In general, a Journey Planner (JP) is designed to meet the specific social- and political objectives of a community, while striving to achieve the following:

- Improve transit services and visibility within the community.
- Increase transit ridership and revenues.
- Assist travellers with choice of travel mode based on real time and accurate information.
- Reduce intermodal travel times and delays for individual travellers.
- Reduce traveller stress for trips to unfamiliar destinations.
- Reduce crash risk and the probability of fatalities occurring.
- Reduce overall system travel times and delays.
- Reduce system costs through public-private partnerships.

2.7.2 A TECHNOLOGY APPROACH TO ATTAINING MULTIMODAL TRANSPORT

As mentioned previously, in order to meet the integration requirements imposed by multimodal transport, a centralised database, which acts as a data hub repository for all modes of transport, needs to be created. If such a database exists, the development of a JP may be spurred on and more people may be encouraged to take advantage of multimodal transport.

The realisation of multimodal transport is thus dependent on technology. That is, the usage of technology to obtain data, then the transformation of the data to information that is valued by the traveller, and lastly, the presentation of this information in a manner most suitable to the traveller.

Fortunately, with the evolvement of information technology, immense scope for growth in the utilisation of information systems, within the transport industry, has been created. And as a result, new integrated approaches needed in attaining multimodal transport, that are available on various information service media, accessible from anywhere, and that provide travellers with the appropriate personalised information, can, accordingly, be catered for. For example: Automated Fare Collection (AFC) systems can be used to mine, and thus reveal, individual differences in travel patterns. Furthermore, if AFC is used in conjunction with RFID technology, transport users can be provided with personalised information about their chosen route(s) (e.g. the provision of personalised trip time estimates and relevant notifications).

All of these emerging and evolving information technologies, have undoubtedly developed new avenues and have made provision for the establishment and realisation of a multimodal transport system.

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3.1. WHY THE COCT?

3.1.1. BACKGROUND TO THE COCT'S ECONOMIC POSITION

The City of Cape Town (CoCT) provides services to approximately 3.5 million people in over 800 000 households and jobs to 1.1 million people. It generates approximately 76% of the Western Cape's GRP (Gross Regional Product) and 11% of the country's GDP (Gross Domestic Product). In

2005, the total exports from Cape Town amounted to R25.4 million while the value of imports amounted to R50.79 million (CoCT 2009). The City therefore clearly plays an important role locally, regionally, nationally and internationally.

3.2. THE COCT'S PRIVATE TRANSPORT NETWORK

The CoCT's road network forms an integral part of its greater transport network. It is the public's right of way system by means of which most of the City's transport needs are met. That is, the movement of people and goods.

According to CoCT (2009), the City has a well-developed road network, estimated at over 8 500 km of public roads, which has strong radial routes focused on the CBD (Central Business District). The two main freeways, the N1 and N2, run from the CBD in a north-east and south-east direction respectively. The speed limits along these roads are generally 120 km/h. Four other freeways, the M3, the M5, the N7/M7 and the R300, act as link roads and primarily run in a north-south direction. Except for the R300, which is circumferential, these are also essentially radially oriented with respect to the CBD. The speed limits on these roads vary from 80 km/h to 120 km/h. The R27 (i.e. Marine Drive) along the Atlantic coast is also an important and heavily used road as it links the CBD with the rapidly growing Table View area.

In CoCT (2009) it is stated that the City's current vehicle count reflects an average annual growth rate of approximately 3.8% in licensed vehicles since February 2002. The present car ownership is about 200 cars per 1000 people. Given these levels of car ownership, the fact that many residential suburbs are located on the fringe of the metropole, the lack of attractive public transport alternatives, and the convenience of private transport, the car still retains a major share of the modal split between private- and public transport.

3.3. THE COCT'S NONRAPID PUBLIC (LAND) TRANSPORT NETWORK

The CoCT has a relatively extensive, but a below par integrated, public transport network. The backbone of the City's public transport network is its rail system. The rail network is operated by Metrorail, a division of PRASA: Passenger Rail Agency of South Africa, and serves 70% of the metropolitan area (CoCT 2009). The bus service, operated by Golden Arrow Bus Services (GABS), provides transport across the greater part of the metropolitan area. Both the rail- and bus services are subsidised by the Provincial Government of the Western Cape (PGWC). Unsubsidised services are provided by the minibus taxis. The minibus taxis operate over most of the metropolitan area and hence provides greater penetration than other public transport modes, especially in low income, high-density residential areas. The City also has an active metered-taxi component, one that has recently seen some growth in demand with the commencement of shared metered-taxi services. Metered-taxis are often used by tourists and business visitors, because they provide a personalised door-to-door service.

For the purpose of this research project, only the City's rail- and bus services will be discussed in more detail.

3.3.1. THE RAIL NETWORK

The track infrastructure of the Cape metropolitan railway system comprises 581 km of Cape Gauge track (1 065mm) with 631 line turnouts, 521 yard turnouts and 121 yard track-kms. The railway signal system comprises 1 473 signals that are based on a combination of technologies. Approximately 80% of the network is equipped with Centralised Traffic Control (CTC), examples of which are: automatic train routing, bi-directional signalling and electronic train registering. There are a total of 42 signal inter-lockings, including several junctions where branch lines merge. Signal blocks are approximately 1 km in length, permitting a nominal headway of 3 minutes on most of the mainline tracks close to the CBD (CoCT 2009).

RAIL NETWORK PERFORMANCE

According to the 2007 Current Public Transport Record (CPTR) given in CoCT (2009), a total of 634 837 daily passengers for both AM and PM peak periods (104 829 Metro Plus and 530 008 Metro class passengers) were recorded. These figures are very similar to the 2004 census which records a total of 621 285 passengers for the same periods. The problem is that, even though the rail system can operate at speeds far in excess of those achieved on much of the road network, there is a perception that the rail system is not operating as well as it could operate. This perception, unfortunately, adds to the rise of loss in mode share among the choice riders. Furthermore, the combination of the ageing fleet, theft, vandalism and other incidents, degrades the consistency of the train service performance, and this does not always compare that favourably with other transport modes. Nonetheless, with regard to the most utilised stations, as taken in 2007 during a 24 hour period, Cape Town records a total of 140 733 daily passengers, with the next highest volume occurring at Bellville, with 64 501 daily passengers. Continuing down the list of most utilised stations, there is Mutual (54 981), Bonteheuwel (54 926), Philippi (52 961), Salt River (51 982), Langa (41 555), Maitland (36 324), Nyanga (30 807) and Khayelithsa (29 991) (CoCT 2009).

3.3.2. THE BUS SERVICE

The scheduled bus services in the CoCT are provided exclusively by Golden Arrow Bus Services (GABS). GABS fleet consists of approximately 1160 buses. They operate 5 295 trips per day with up to 270 000 passengers per day on 1 530 routes and on 113 timetables (CoCT 2009).

3.3.3. ACCESS TO PUBLIC TRANSPORT WITHIN THE COCT

Walking is practically always part of a trip: travellers have to walk to and from the stops/stations of the public transport network and when driving by car, travellers are also required to walk to and from the parking place, although these distances might be short. With this in mind, NMT (Non-Motorised Transport) is deemed an important measure in assessing the public transport trip.

The 2004 National Household Survey (NHS) undertaken by the CoCT reported that more than 70% of the people in the City are within a 10 minute walk of the nearest public transport mode and nearly 50% of the residents are within a 5 minute walk of the nearest public transport mode (CoCT 2009). Therefore, in terms of NMT, the current public transport network is adequately served.

3.4. THE COCT'S INTEGRATED TRANSPORT PLAN

3.4.1. THE TRANSPORT PROBLEM

The disadvantages of the current public transport services, as identified in CoCT (2009), are as follows:

- They are concentrated in the morning- and afternoon peak hours, with limited services during the day or late in the evening.
- Their services are not scheduled and there is no integrated ticketing system between the various modes.
- They are linked to major safety issues, with women and children being particularly vulnerable when they use public transport.
- They are subject to inadequate regulation and law enforcement.
- They are not planned as part of an integrated public transport system.

According to CoCT (2009), 40% of trips to work are undertaken by private car travel, and (as indicated by the 2004 NHS undertaken by the CoCT) about 57% of all morning peak period trips include some private car travel. Moreover, the CoCT (2009) states that, compared with the number of public transport passengers entering the CBD in 1991, bus transit has decreased from 16% to 7% and rail transit from 27% to 13%, while the minibus taxi percentage has increased from 6% to 13%. Thus, not only has there been a significant shift to private transport, but also a change within the public transport modes; that is, a shift away from the usage of bus and train to the usage of minibus taxi.

As mentioned previously, driving a car fits the need for individualisation and is mostly a habitual behaviour rather than a rational choice. And once a person becomes more affluent, the importance of owning a car also increases. The minibus taxis provide greater penetration than other public transport services and serve most areas on dedicated routes. Furthermore, its service, although unscheduled, runs frequently and conveniently with numerous pick-up and drop-off points along its routes.

In hope of preventing the fostering of this phenomenon, the City developed its Integrated Transport Plan (ITP) in 2009. One of the most important projects of the ITP is the promotion of an Integrated Rapid Transport (IRT) system. The City hopes that, by promoting an integrated system, with integrated operations, with longer operating hours, greater service frequencies and scheduled services on all routes, the future may hold a more balanced share of modal split between private- and public transport.

3.4.2. THE INTEGRATED RAPID PUBLIC TRANSPORT NETWORK

The CoCT's Integrated Rapid Public Transport Network (IRPTN) commenced in October 2010 when the MyCiTi Business Plan, i.e. stipulated framework for phase 1A, was adopted by the Council (Martheze and Grimbeek CoCT 2011).

Phase 1A is the City's starter phase of its IRPTN. It runs between the CBD and Table View and consists of residential services on feeder routes[10] in the areas around Table View, a trunk route on a special red bus-way between central Cape Town and Table View, and a feeder route around the CBD. With the advent of September 2013, phase 1 is planned to be completed. By then the starter phase will have been extended to the Atlantis corridor as well as to the informal settlements of Du Noon and Joe Slovo Park (Luhanga 2011).

The CoCT's ultimate vision is a citywide-integrated public transport network. To pursue this vision, the City not only has to cater for communities where vehicle ownership is low, but also has to strive to provide more people with access to transport. The attainment of this vision is accompanied by two initiatives. The first is the provision of Non-Motorised Transport (NMT) such as walking and cycling. A network of cycling paths and upgraded pedestrian walkways that connect users to the bus routes, is believed to result in health benefits and lifestyle improvements. And the more people who walk and cycle in the vicinity of the stops and stations, the safer the MyCiTi system will be (MyCiti 2010). The second initiative is to extend the MyCiti network. The allowance of three additional implementation phases has therefore been planned for (CoCT 2009).

[10] A feeder route is a route that provides access to a trunk route (aka a main route).

Phase 2 is planned to bring mobility to some of the most densely populated and poorest communities of the City, by encompassing all areas of the Metro South East and also extending to the Southern Suburbs. And with the completion of phases 3 and 4, the Northern Suburbs, the Delft and Blue Downs areas, as well as the greater Helderberg will also have been incorporated in the MyCiti network (CoCT 2009).

3.5. THE COCT'S MANAGEMENT FACILITY WITH RESULTANT TRANSPORT DATA REPOSITORY

The Transport Management Centre (TMC) of the CoCT was officially opened in May 2010 and is situated in Goodwood. It is the first integrated public transport, traffic and safety and security management centre in South Africa, and is also viewed as one of the finest state of the art facilities in the world (CoCT 2010).

According to CoCT (2010), the TMC has five main functional areas, namely:

1. Freeway Management System (FMS).

The TMC uses 197 CCTV (Closed Circuit Television) cameras to monitor the traffic flow, and 48 VMS (Variable Message Signs) to provide feedback to the travellers. These VMS have been placed throughout the City, of which some use renewable energy sources such as wind and solar power.

2. Arterial Management System (AMS)/ Urban Traffic Control (UCT).

The TMC uses traffic signal controls, with aid of the CCTV cameras, in order to keep the traffic in the City moving seamlessly.

3. Integrated Incident Management (IIM).

The TMC facilitates faster emergency- and incident responses by detecting incidents quickly and notifying relevant role players immediately via an advanced, modern dispatching system.

4. Integrated Rapid Transport (IRT).

The TMC is seen as the operational hub for the MyCiti System - with central processing, vehicle monitoring, computer-aided dispatch, vehicle scheduling, database and reporting, information management, digital video management, communication-monitoring, and emergency and maintenance control.

5. Transport Information Centre (TIC).

The TMC has a 24 hour, 7 day a week, service that provides information to citizens and visitors on general enquiries of public transport by attending to all the feedback for: Cape Metrorail, Golden

Arrow Bus Services (GABS), Park-and-Ride facilities, Dial-a-Ride public transport and kerbside parking management.

The CoCT is therefore in a privileged position:

- The City has an operational transport data centre that has sufficient space available for expansion if needed.
- The City has a Transport Information Centre (TIC) that already provides citizens with some information on public transport.
- Most of the transport related data are, to a certain extent, contained within the City's TMC.
- Most of the stakeholders involved in the CoCT's transport industry are presently participating members of the TMC.

With all these features at the City's disposal, the scope for further enhancement is therefore vast. These features offer a sufficient base and point of departure for the promotion of multimodal transport and will hence provide the necessary stimulus for the realisation of a sustainable integrated land transport system. However, in order to understand the scope of the problem at hand, the flow of information within the City's transport environment needs to be understood. Refer to Figure 8.

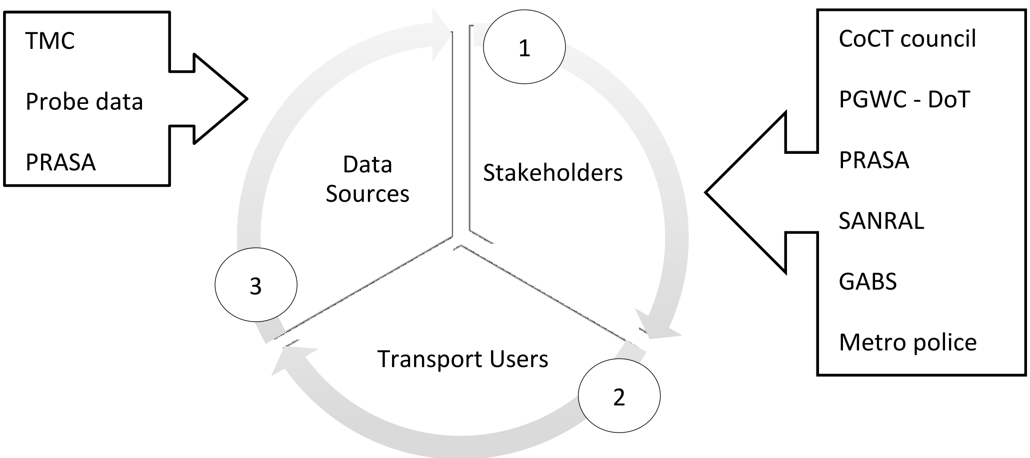

FIGURE 8: THE FLOW OF INFORMATION

This author believes that the attainment of a sustainable integrated land transport system is dependent on understanding the relationships between the three facets of Figure 8:

1. Proper support, participation and involvement of the associated transport stakeholders are cardinal to the realisation of an interoperable transport system.
2. The feasibility of a multimodal transport system is dependent on the transport users' opinion thereof as well as aligning it with, and therefore providing a service that caters

for, their needs. That is, with multimodal transport, a service that spans across all modes of transport.

3. In order to meet this need for unconstrained information, a centralised (intermodal) database needs to be in place. Therefore, the extent of the current data sources available and the standard used in each, need to be known and understood.

By considering these three facets, the successful implementation and provision of multimodal transport, with the necessary provision of trip information to the travellers, will be possible.

3.6. THE COCT'S TRANSPORT REPORTING SYSTEM

In March 2010, the City of Cape Town (CoCT) put out a tender seeking assistance with the collection, capture, analysis and presentation of transport data for the update of the 2007 Integrated Transport Plan (ITP) (Springleer *et al.* 2012). And in order to be best positioned to produce data for inclusion into the Transport Register, the CoCT's Transport Department initiated the development of the Transport Reporting System (TRS).

Before the initiation of this tender, the City experienced a number of problems that arose from its transport data being housed in many separate sub-systems. According to Springleer *et al.* (2012), the City experienced difficulty in handling and managing the transport data due to differing levels of technology and database platforms, difficulty in extending these existing systems to accommodate new functionality and reporting abilities as well as difficulty in integrating, reporting and consolidating the information in these systems for management review.

After a public tendering process, a team of consulting engineers, along with their specialist Geographical Information System (GIS) subcontractor, were appointed, on a three year contract, to commence with the development of the TRS as of 1 July 2010 (Springleer *et al.* 2012).

After initial assessment, the tender team linked the City's problems to the following setbacks: the vintage of data, the availability of data, the storage of data and the integrity of data. (For example, the data that was previously recorded was only captured after some time had elapsed. As a result, the relevance of the data came into question.) Springleer *et al.* (2012) identified the main reason for the inefficiencies in the data to be related to the fact that both the survey and capturing were often carried out by the same staff. Furthermore, capturing was carried out on various spreadsheets that needed to be combined, cleaned and managed. This then often led to files being lost, overwritten, or captured more than once.

The development of the TRS aims to mitigate these inefficiencies by allowing online capturing of data onto a web-based database (DB). This DB can then facilitate the TRS with integrating and consolidating the transport survey data into a central DB in order to make the data and reports easily accessible to people within the City's Transport Department (Springleer *et al.* 2012). The key benefit of implementing the TRS is thus the creation of automatic reports and the quick access to information. Springleer *et al.* (2012) define the main types of reporting abilities (available within the TRS) to be the following:

- Raw survey data extractions for ad-hoc use such as modelling.
- Custom text and graph reports for various metrics: e.g. supply and demand, modal usages and vehicle occupancies.
- Spatial or GIS based reports that filter vast amounts of data into easy to interpret map-based views.

The summary of the system improvements, which have so far resulted from the implementation of the TRS, can be seen in Table 3 (Springleer *et al.* 2012).

TABLE 3: SUMMARY OF SYSTEM IMPROVEMENTS BY THE TRS

Concerns	Advancements	Shortcomings
Vintage of data	Data is recorded and uploaded on a web-based database from which it is immediately available for extraction and analysis by the user. Certain modes are available instantly, such as the bus module, which makes use of portable electronic GPS enabled storage devices.	Currently, not all recorded data is captured at the same rate. However, a possible future consideration for the improvement thereof is to research the possibility of automating data collection and capturing as much data as possible.
Availability of data	Once captured, data is immediately available to various users. And depending on the public transport mode, the data output is made available in at least one of the following formats: automatic report, pdf, Microsoft Word and Microsoft Excel.	The current availability of captured raw data is excellent. However, certain public transport modes require an internal (i.e. within the CoCT) validation, such as the cleaning and matching process of the minibus taxi module. Nevertheless, when compared to the way it was previously done, this process has been automated to a large extent. Notwithstanding this, in order to fulfil the legislative requirements, the process will have to be undertaken by a City official and cannot be outsourced.
Storage of data	Data is stored on a central server running Microsoft SQL Server as the database platform.	Access to the data is currently only available via an internet connection. However, the connectivity and internet speed within the City's IT infrastructure are continuously improving. Consequently, within the near future, the sufficiency of this access type is deemed to improve.
Integrity of data	Electronic data trails are available for all inserts, extractions, printing of permits, and so on. Furthermore, all modifications or alterations can be detected and isolated for auditing purposes. And with the raw data capture sheets being uploaded to the TRS, scans can also be downloaded for reference purposes.	Unfortunately, checks and balances, for a system like the TRS, will never ensure 100% integrity. However, when compared to what was previously done to ensure data integrity, this issue is indeed addressed to a large extent.

More specifically, within one year of employment, Springleer *et al.* (2012) state that the TRS has aided the City's Transport Department in achieving the following:

- The City officials have gained the ability to both improve the management of their data, and to respond quicker and more efficiently to various enquiries.
- The City is now capable to make survey data and reports available within a week of field surveys being completed, in addition to the data being protected and controlled in a transparent and auditable manner.
- Data is now easily accessed via the internet and automatic reports are generated to assist with the compilation of the Current Public Transport Records (CPTR).

3.7. THE COCT'S UNIMODAL JOURNEY PLANNERS

3.7.1. INFORMATION ON PRIVATE TRANSPORT

GOOGLE TRAFFIC

According to (SAinfo reporter 2012), car drivers in Johannesburg, Pretoria and Cape Town can now plan their commuting by accessing live traffic updates through Google Maps. Furthermore, as Google is constantly updating and improving its coverage, it is expected that other South African cities will be able to access this service in the near future.

Car drivers can obtain information about live traffic conditions by visiting maps.google.co.za and activating the traffic layer in the widget on the upper right-hand side of the map. This traffic information is also available on mobile devices by selecting the 'view traffic' option.

The traffic data presented by Google Maps allows users to view the current traffic conditions, and also provides them with estimated travel times. The live traffic coverage uses crowd-sourcing and features a colour-coded rating system on a scale from slow to fast. That is, data such as the speed the car is travelling at (which is received from GPS-enabled mobile users), is analysed and compiled into information car drivers can use in planning their commuting. Moreover, it is believed that, as GPS-enabled mobile phones and data plans get less expensive, more people will be able to partake. As a result, the traffic data portrayed can become more comprehensive and accurate, which in turn may allow the application and scope of this software to become vast.

Refer to Figure 9.

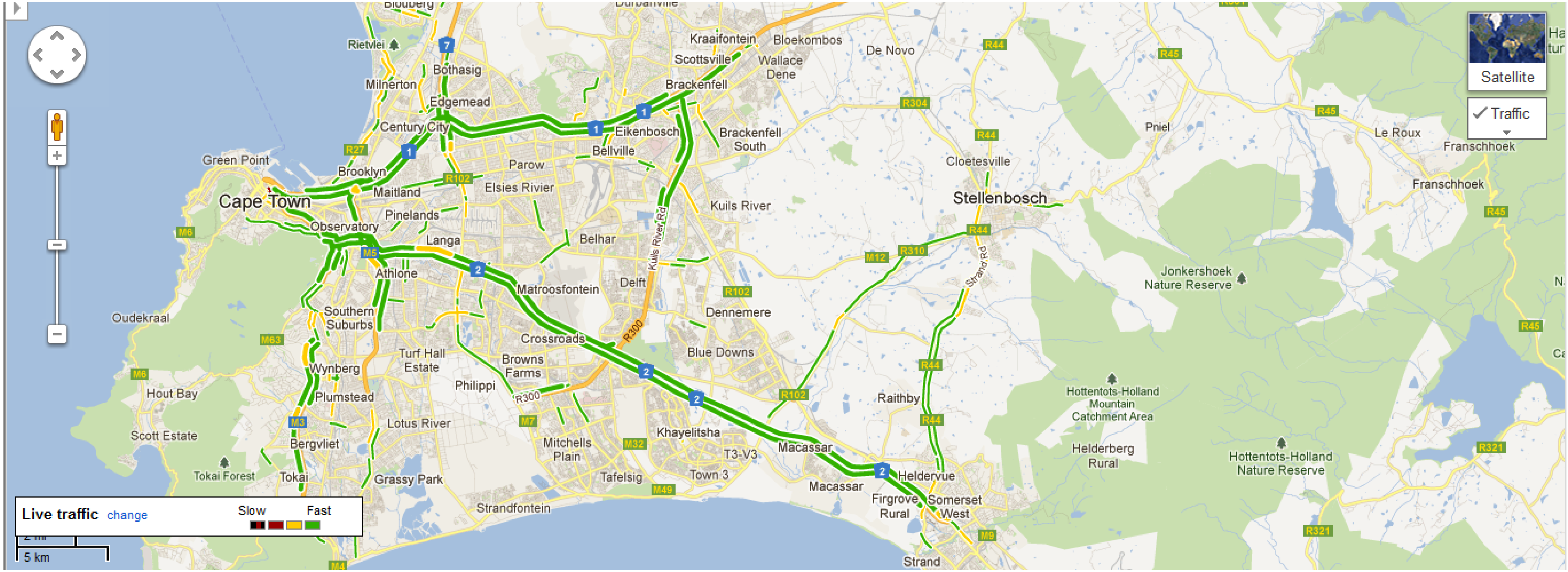

FIGURE 9: GOOGLE TRAFFIC UPDATES FOR THE COCT

TOMTOM: LIVE TRAFFIC

TomTom has a similar application to that of Google Maps that can be viewed at www.tomtom.com/livetraffic. However, TomTom's version has a wider scope of application. The car drivers are not only provided with traffic flow information, but also time estimates on delays, as well as information about the length of a queue on a specific road segment. Moreover, the usage of this application is also extended to TomTom GPS devices with the TomTom HD (High Definition) traffic application.

Detailed information such as: incident reports about the length and reason of the delays, the most accurate delay information (refreshes every 2 minutes), travel- and arrival times, and alternative route proposals, is sent directly to the car driver's TomTom navigation system. (TomTom 2012). However, the scope and accuracy of this data is also dependent on the number of probes. Nonetheless, TomTom HD Traffic is seen as a revolution in traffic information that offers travellers the best coverage, the most updates from the best sources, and it is fully automated. If there is a quicker or better route, TomTom HD will find it.

3.7.2. INFORMATION ON PUBLIC TRANSPORT

METRORAIL

Metrorail users can access their website at www.capemetrorail.co.za. Refer to Figure 10.

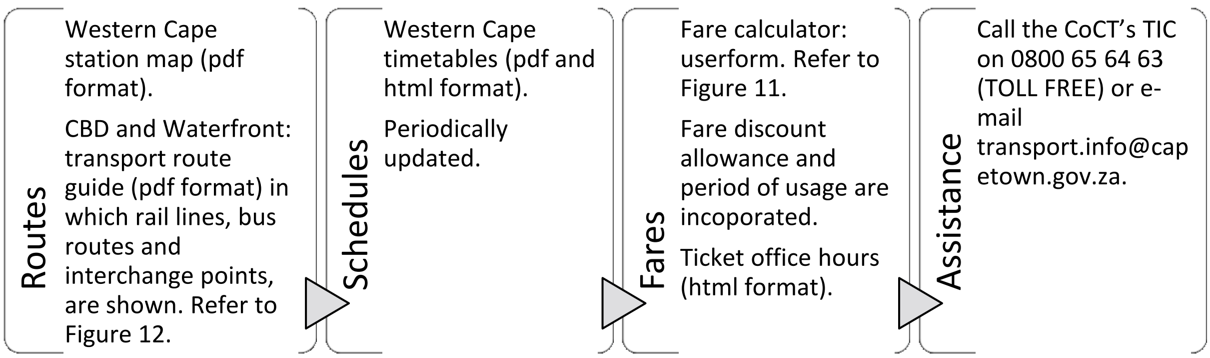

FIGURE 10: METRORAIL'S WEBSITE

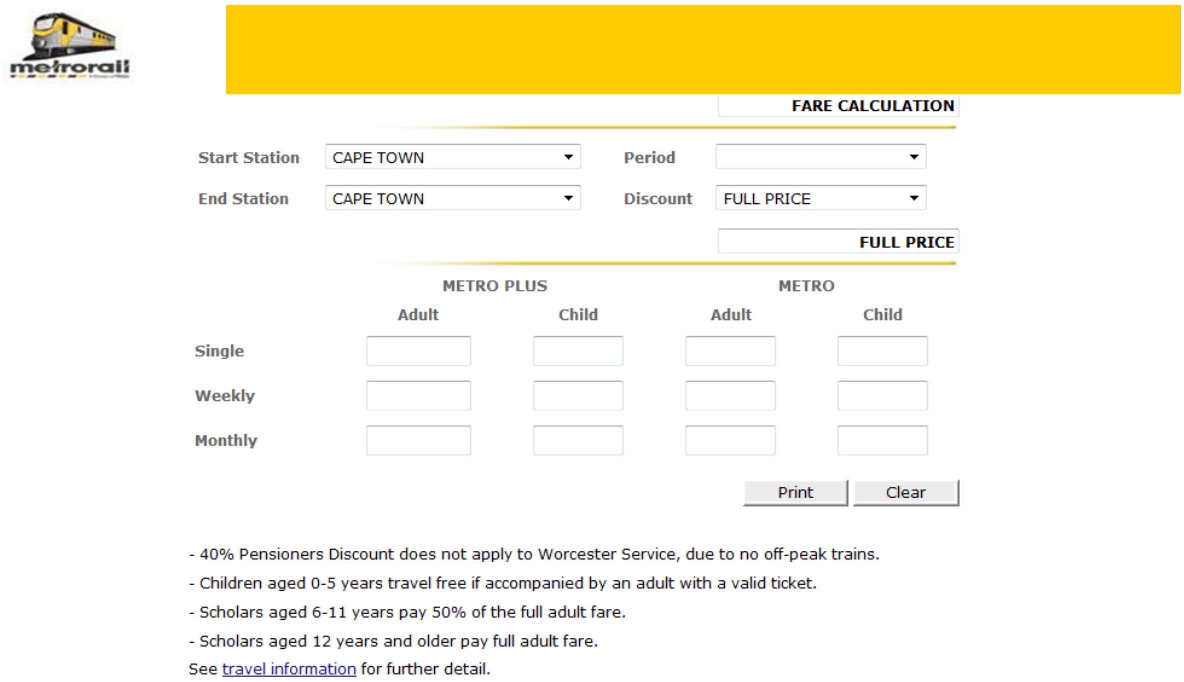

FIGURE 11: METRORAIL FARE CALCULATOR

GO METRO: MOBILE PHONE APPLICATION

Metrorail Western Cape announced a new mobile information service in September 2012. According to Mthuthuzeli Swartz, Regional Manager of Metrorail, the results of a recent survey confirmed that 92% of regional rail commuters have mobile phones and can thus benefit from this new service.

The complete service is scheduled to be ready early 2013. However, in the next few months, travellers have the opportunity to test the service in its current format. Travellers can already access easy-to-use train schedules, a trip planner and fare calculator by visiting www.gometro.co.za. Moreover, this site is regularly updated to reflect changes to the scheduled service, average delays per service corridor, as well as daily maintenance programs (Metrorail 2012).

Justin Coetzee, founder of Go Metro, believes that Go Metro puts Metrorail Western Cape on par with transport services around the world, because travellers can now, whether at home, work, in a transit or at a stop/station, have instant access to information on Metrorail's services.

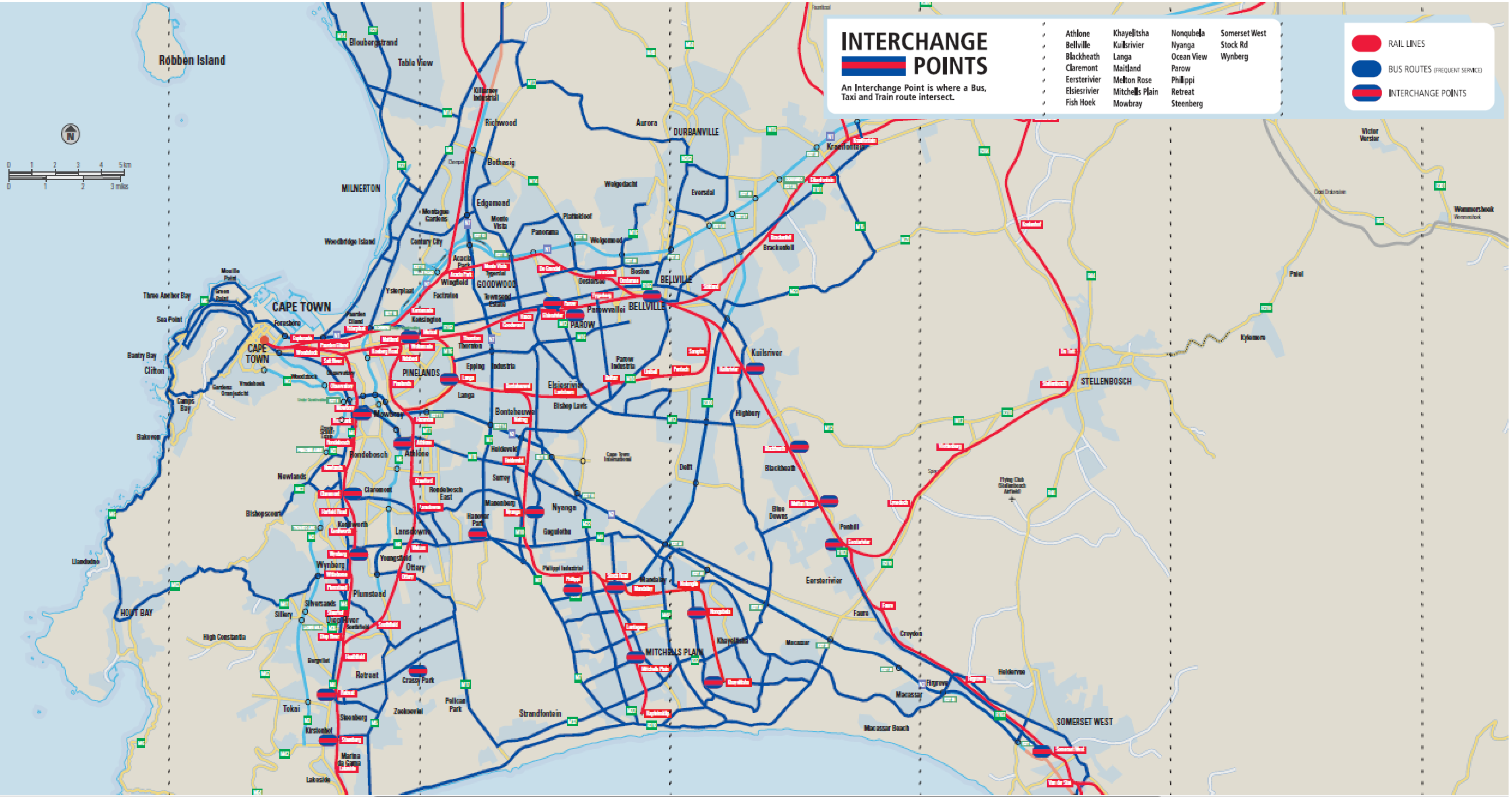

FIGURE 12: TRANSPORT ROUTE GUIDE

Golden Arrow Bus Services (GABS) users can access their website at www.gabs.co.za. Refer to Figure 13.

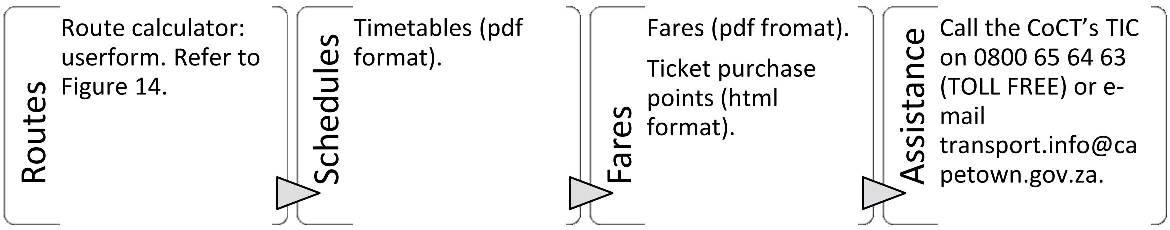

FIGURE 13: GABS' WEBSITE

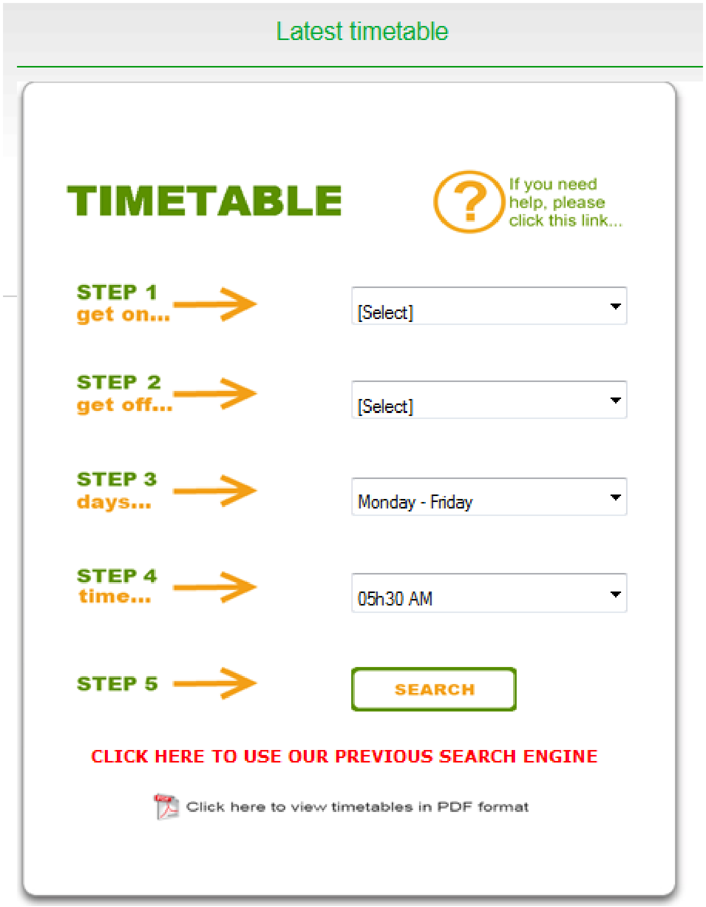

FIGURE 14: GABS ROUTE CALCULATOR

MYCITI

MyCiti users can access their website at www.capetown.gov.za/en/MyCiti. Refer to Figure 15.

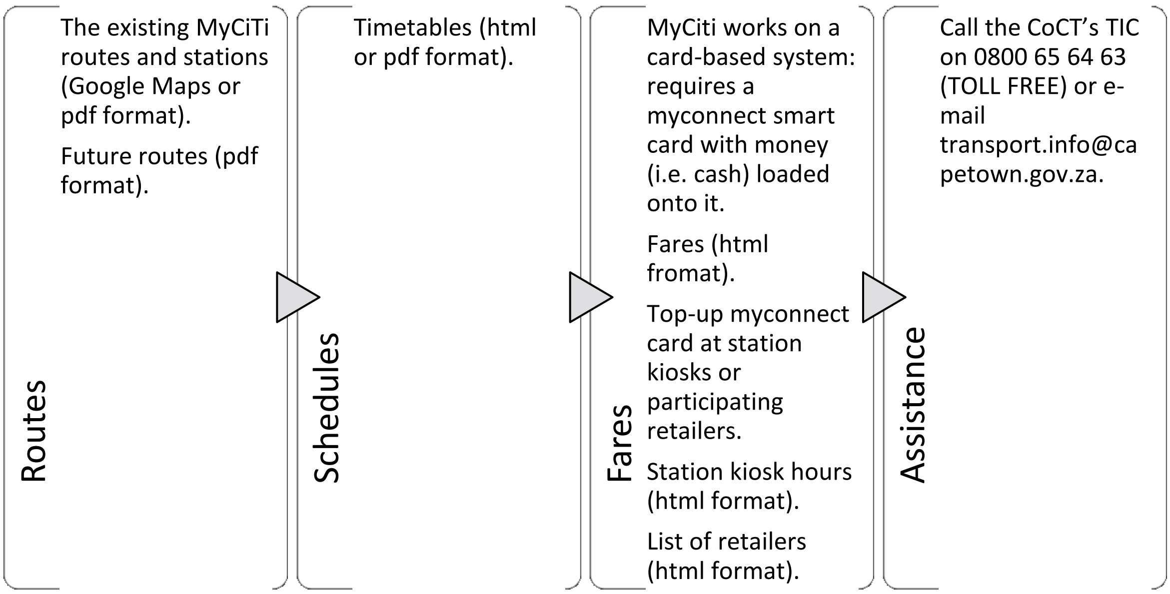

FIGURE 15: MYCITI WEBSITE

GARMIN: CITYXPLORER

The cityXplorer application for Garmin GPS devices is a street navigator that features enhanced pedestrian navigation. The application gives the travellers the ability to traverse seamlessly by using various public transport mode options. The available regions, for which this application can be used, are listed below (Garmin 2012):

- North America
- South America
- Europe
- Asia
- Australia
- South Africa

The South Africa region encompasses Cape Town and Johannesburg, with the public transport modes related thereto being; walking, train, bus or a combination of these options. The user can activate the CityXplorer application on his/her Garmin GPS by selecting the pedestrian mode option. This application includes detailed coverage for the greater Cape Town area, including, among others, Cape Town International airport, and the cities of: Grassy Park, Newlands, Durbanville, Bellville, Blackheath. Refer to Figure 16 (Garmin 2012).

FIGURE 16: COVERAGE AREA OF CITYXPLORER

The utilisation of this application within the Cape Town region is however relatively limited: firstly due to the limited span of the City's public transport networks, and secondly due to the fact that the current data contained within this application being incomplete; e.g. insufficient data regarding GABS stops. Nonetheless, the concept of the cityXplorer application (expanded with the inclusion of the private vehicle) relates to the sought after multimodal journey planner researched herein.

3.8. THE COCT'S CONSOLIDATED JOURNEY PLANNER

3.8.1. FINDMYWAY: MOBILE PHONE APPLICATION

Cape Town's public transport commuters can now use their mobile phones to access (real time) timetables to plan their routes by visiting www.findmyway.mobi.

FindMyWay is a free public service website specifically designed to make the lives of commuters easier by allowing them access to information on all modes of public transport (e.g. Metrorail, GABS, MyCiti, metered-taxi) from their mobile phones (Jooste and Tswanya 2012).

According to transport MEC (Member of the Executive Council) Robin Carlisle, FindMyWay would benefit the majority of commuting Capetonians since 92% of people in the province have access to a mobile phone.

FindMyWay is the first one-stop portal of public transport- and commuter information in Cape Town that brings together all the modes of transport within the City. It should however be noted that, even though this websites consolidates transport information (i.e. commuters can easily access transport information from one portal), it does not integrate it in a manner applicable to multimodal transport.

3.9 THE MAIN CONSIDERATIONS DRAWN FROM THE RESEARCH

The main considerations drawn from the status quo research conducted, and their associated contribution toward the proposition made herein, are discussed in the following section.

3.9.1 THE FOUNDATION FOR THE RESEARCH PROPOSITION

From the aforementioned research, two important aspects, that stimulate the proposition made herein, are evident.

The foremost important aspect found is the fact that data, in historic- and real time format, is available. Information such as schedules, fares, and routes, can be found on the websites of the public transport modes discussed herein (i.e. MyCiti, GABS and Metrorail). And even though this information is generally portrayed to the public transport user in a decentralised manner, the data of these modes are all contained, to a certain degree, at the TIC (Transport Information Centre) in the CoCT's TMC (Transport Management Centre). This, evidently, makes the scope for improvement vast and also supports the proposition made herein. Furthermore, the freeways are, with aid of ATMS (Advanced Traffic Management Systems), monitored with real time accuracy; GPS tracking in MyCiti buses and Metrorail trains allow for real time information on the position of each unit in their respective fleets; and the call centre, promoted by the TIC, provides, to a certain degree, up to date information on general enquiries of public transport.

The second aspect found is that there is an unmistakable rise in the demand for centralised data. As mentioned previously, with the development of the Transport Reporting System (TRS) in March 2010, the City has since acknowledged that a number of its transport related problems experienced, originates from its transport data being housed in many separate sub-systems. Furthermore, in October 2012, the City has accordingly launched a new transport authority, which aims to bring the City's public transport network under one management system, with a single contracting authority. That is, the City intends to introduce an integrated public transport system. Following from this, the first one-stop portal of public transport- and commuter information in Cape Town, that brings together all the modes of transport within the City, was launched in November 2012. And even though this website (i.e. FindMyWay) does not integrate the transport data in a manner applicable to multimodal transport, it does however emphasise the direction the transport environment is moving towards. That is, a multimodal platform.

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4.1. INTRODUCTION

Given the research stipulated in the previous sections, this section thus considers, in detail, a discussion of all the portraying aspects required in obtaining multimodal transport. The main focus areas considered are: 1) the multimodal transport network and the design and modelling thereof, 2) the role of Intelligent Transport Systems (ITS) in achieving a multimodal platform, 3) the need for and the design criteria of a (centralised) database, and 4) the need for and the travel information requirements of a multimodal Journey Planner (JP). The subcomponents in each of the main focus areas, with their corresponding considerations as well as their related foundations, are highlighted in this section. This section thus investigates each of the relevant contributing aspects, individually, and depicts the general line of thought needed in accomplishing multimodal transport. At the end of this section, these aspects are integrated in order to develop a generic (sequential) framework that simplifies the implementation of multimodal transport.

4.2. THE MULTIMODAL TRANSPORT NETWORK DESIGN

4.2.1. THE HIERARCHICAL (MULTILEVEL) NETWORK APPROACH

Multilevel transport networks and multimodal transport networks are strongly related. Van Nes (2002) states that, when a mode is used to access another mode, a hierarchical relationship between these two modes, and thus between the network levels that are used, is introduced. This multilevel network configuration is illustrated in Figure 17 (Van Nes 2002).

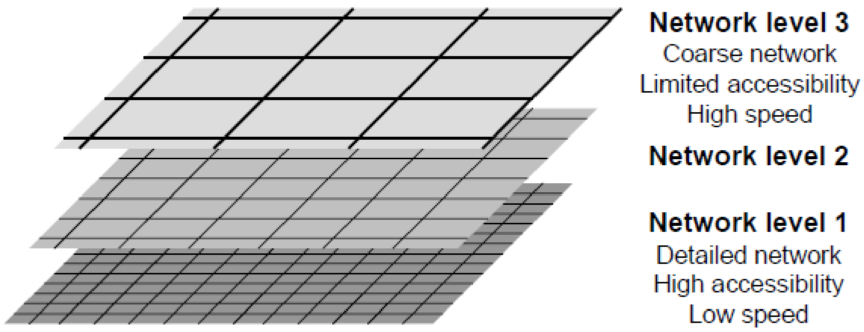


FIGURE 17: ILLUSTRATION OF MULTILEVEL NETWORK

The modelling of multimodal transport networks as multilevel transport networks is however difficult. According to Van Nes (2002), the idea of hierarchy implies that a transport network, apart from having its own function, also provides access to higher level networks. And by incorporating the network characteristics denoted in Figure 17 (Van Nes 2002), it is evident that the higher-level networks are suitable for long distance trips, whereas the lower-level networks are suitable for short distance trips and/or for accessing higher network levels. Consequently, the quality of the lower-level network is determined by the quality of the higher-level network. And since travellers may traverse between network levels, the quality of the higher-level network also influences the patronage of the lower network. Furthermore, multilevel transport design deals with both the transport- and the traffic service networks. This adds to the complexity of the design problem. Van Nes (2002) states that the transport- and the traffic service networks are not only interrelated through the traffic market that exists between them (as is depicted in Figure 4), but the transport service networks also require the traffic service network. For example: new links in a road network, enable new public transport services by for example bus, which in turn might reduce the need for building those links. This inducement of extra transport services also introduces a mode choice problem: *which of the transport services are used by which travellers to access the higher-level networks?*

Evidently, the hierarchical (multilevel) approach to modelling multimodal transport networks is a complex one. If one however transforms the design problem into a single-level urban transport system, the complexity of the design problem is considerably reduced. One of the methods identified in Van Nes (2002), is to model the multimodal transport network as a supernetwork (also sometimes referred to as a hypernetwork).

4.2.2. THE SUPERNETWORK APPROACH

Supernetworks are *networks of networks* that are *above and beyond* existing classical networks. Supernetworks consist of nodes, links, and flows, with nodes corresponding to locations in space, links to connections in the form of roads, cables, etc., and flows to vehicles, data, and so on. According to Nagurney and Smith (2011), supernetworks are conceptual in scope, graphical in perspective, and, with the accompanying theory, predictive in nature.

Nagurney and Smith (2011) state that, if one harnesses the concept of a supernetwork, one will gain the insight and power to:

- dentify similarities and differences in distinct problems through understanding their underlying network structure, and
- apply efficient network algorithms that relate to the large-scale network problems of today.

THE TRANSPORT SUPERNETWORK

Transport networks are complex dynamic systems. And as mentioned previously, the decisions of individual travellers are influenced by the transport network design. As a result, the design of the transport network determines the mode choice characteristics of the travellers, which in turn affects the efficiency and productivity of the entire transport system. According to Nagurney and Smith (2011), these travel alternatives can be appropriately captured by modelling the transport network as a supernetwork.

The transport supernetwork is an abstract concatenation[11] of transport networks interconnected by transfer links, where the origins and destinations correspond to appropriately defined nodes, the links (having associated disutilities: e.g. time or distance) connect the nodes, and the paths being comprised of (directed) links that connect the origins and destinations (Nagurney and Smith 2011). Refer to Figure 18 (Carlier *et al.* 2002).

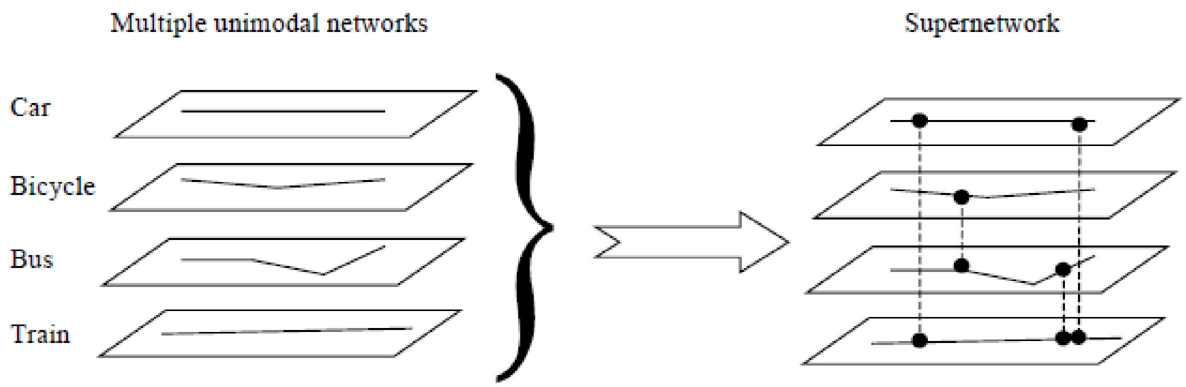


FIGURE 18: DEFINING A SUPERNETWORK

The unimodal networks contained in a supernetwork correspond to the travellers' mode choice alternatives and the transfer links, not only stand for the physical transfer between the modes, but also relate to the travellers' mode choice characteristics, i.e. the time, distance and/or restrictions of transferring between the alternatives (Carlier *et al.* 2002). Therefore, by modelling the transport networks as a supernetwork, the distinction between mode choice and route choice (as is the case in the hierarchical approach) is replaced by a route choice problem only.

4.3. THE FOUNDATION FOR MODELLING THE MULTIMODAL TRANSPORT SUPERNETWORK

Multimodal journeys are a common travel phenomenon, which, as mentioned previously, are expected to become more important because of their anticipated contribution to sustainable urban transport. However, Liao *et al.* (2009) state that, the multi-dimensional nature of multimodal journeys, due to the complicated choice behaviour in executing multiple activities, renders travel planning more difficult and thus makes the modelling of multimodal travelling a complex problem.

In order to model a multimodal transport supernetwork, the concepts of Graph Theory and Finite State Automata need to be understood.

[11] To connect or link in a series or chain.

4.3.1. GRAPH THEORY

GENERAL GRAPH THEORY

GRAPHS, EDGES AND VERTICES

Ruohonen (2008) defines a graph as a pair of sets G = (V, E), where V is the set of vertices (aka nodes) and E is the set of edges (aka links), formed by pairs of vertices. An example of a graph is depicted in Figure 19 (Ruohonen 2008).

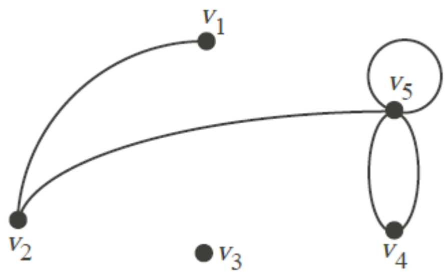


FIGURE 19: EXAMPLE OF AN (UNDIRECTED) GRAPH

The set of vertices and edges, which relate to Figure 19 (Ruohonen 2008), are:

$V = \{v_1, \ldots, v_5\}$

$E = \{(v_1, v_2), (v_2, v_5), (v_5, v_5), (v_5, v_4), (v_5, v_4)\}$.

Edge Attributes

Each edge e ∈ E has two attributes: $\ell(e)$ and $w(e)$. The attribute $\ell(e)$ denotes the label of edge e and is usually drawn from a (fixed) finite alphabet Σ. And the attribute $w(e)$ denotes the weight of an edge and is expressed as nonnegative integers (Barrett *et al.* 2000).

PATH

A path *p* of length k from u to v in G is a sequence of edges $(e_1, e_2, \ldots, e_k)$, such that $e_1 = (u, v_1)$, $e_k = (v_{k-1}, v)$, and $e_i = (v_{i-1}, v_i)$ for $1 < i < k$. Now, given a path $p = (e_1, e_2, \ldots, e_k)$, let $w(p)$ and $\ell(p)$ denote the weight- and the label of *p* respectively. The weight of the path is given by $_{1\leq i\leq k}\, w(e_i)$ and the label of *p* is defined as $\ell(e_1) \cdot \ell(e_2) \cdots \ell(e_k)$. Therefore, the weight of a path is obtained by summing the weights of the edges and the label of the path by concatenating the labels of the edges on the path in their natural order. Furthermore, a path is **simple** if all the vertices in the path are distinct, i.e. a vertex is never repeated (Barrett *et al.* 2000).

DIRECTED- AND UNDIRECTED GRAPHS

In an undirected graph, the sequence of the edges is not important and hence no sense of direction exist; whereas in a directed graph (also referred to as a digraph), the vertices are connected by directed edges. Thus, with a directed graph, the elements of E are ordered pairs: the edge from vertex u to vertex v is written as (u, v) and the other pair (v, u) is the opposite direction edge (Ruohonen 2008).

SOURCE AND SINK

Given an edge (u, v), the initial vertex (i.e. vertex u) is referred to as the source and the terminal vertex (i.e. vertex v) as the sink. Furthermore, in a directed graph, a source has an in-degree (the number of edges into the vertex) of zero and a sink has an out-degree (the number of edges out of the vertex) of zero (Ruohonen 2008).

GRAPH THEORY RELATED TO MULTIMODAL TRANSPORT

WALKING

Walking is practically always part of a journey: travellers have to walk to and from the stops/stations of the public transport network and when driving by car, travellers are also required to walk to and from the parking place, although these distances might be short.

Van Nes (2002) thus states that walking should be considered as a universal component at the start and the end of any journey and not as a separate mode in the definition of a multimodal journey. Travellers who walk to the bus stop, ride the bus, and walk from the stop to their destination thus make a unimodal trip. Van Nes (2002) further states that, the only exception to this rule is when walking can be seen as the main mode of the journey. That is, when walking is the mode used to conduct the largest distance of the journey. Furthermore, in the case that a bicycle is used to access the public transport network, Van Nes (2002) states that it should be considered as a multimodal trip in which two services and two modes (i.e. a bicycle and for instance a bus) are used.

MULTIMODAL TRIP VERSUS -TOUR

According to Van Nes (2002), the definition of multimodal transport should ideally be based on tours (aka journeys) and not on trips. As can be seen in Figure 20 (Van Nes 2002), a tour may consist of one or more trips.

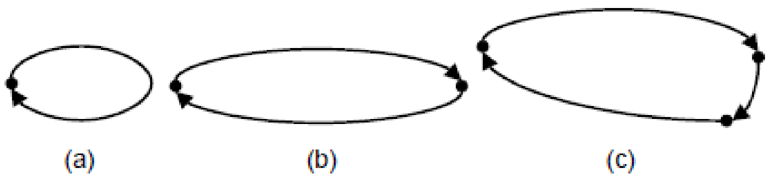


FIGURE 20: EXAMPLES OF TOURS CONSISTING OF 1(A), 2(B) AND 3(C) TRIPS

A multimodal tour occurs when the first part of a tour is made by some mode of transport and the return part by a different mode of transport. For example, if a bus is used in the first trip and a car in the return trip, a multimodal tour consisting of two unimodal trips is conducted. If the first- or the return part however consists of two or more modes within the single part, it is referred to as a multimodal trip.

See Figure 21 (Van Nes 2002). The dotted arrows therein depict walking. And as mentioned previously, it is not considered as a separate mode of transport due to it almost always being part of a trip or tour.

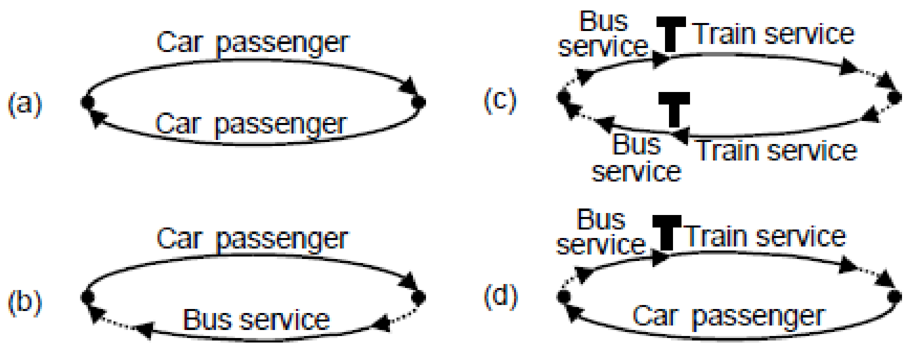


FIGURE 21: EXAMPLES OF UNIMODAL- AND MULTIMODAL TOURS

In Figure 21 (Van Nes 2002), (a) represents an unimodal tour consisting of two unimodal trips, (b) represents a multimodal tour consisting of two unimodal trips, (c) represents a multimodal tour of two multimodal trips and (d) represents a multimodal tour consisting of both a multimodal- and a unimodal trip.

TRANSFERS

Transfers are an essential part of multimodal trips and -tours. A transfer occurs when travellers change transport service networks or transport modes.

According to Van Nes (2002), when the traveller change transport mode, a **multimodal transfer** occurs; and when the traveller change transport service network, an **intramodal transfer** occurs. Multimodal transfers are special because they deal with different network types, which are designed separately by different operators or authorities; whereas for intramodal transfers, usually one organisation is responsible for all these aspects (Van Nes 2002). A typical example of an intramodal transfer is the transfer from a regional bus to an urban bus. And even though such transfers are not abundant in South Africa, it is included herein for the sake of thoroughness.

GRAPH MODELS

TIME INDEPENDENT GRAPHS

Time independent routing has been studied in great detail and, according to Pajor (2009), is mostly used in road networks. In a time independent network, the weight of each edge is given a constant value, such as: travel time, geographical distance or any other appropriate metric.

As an example, suppose that an edge, that represents a road segment in a road network, exists. If one assigns this edge a constant value, a query will always (when using this edge) produce the same result. Pajor (2009) states that, while this is sufficient for certain metrics like geographical distance (the geographical distance of a road segment is not influenced by time), it might not be realistic enough for others. For example, if one uses travel time as a metric, imagine traversing during peak hours in contrast to off-peak hours. During peak hours, the traveller will most likely traverse much longer on the same route due to congestions imposed by the time of travel. Nonetheless, Pajor (2009) states that, in a road network, the absence of time-dependency still yields useful queries; whereas other models, like those for railway timetables, most certainly do not.

TIME DEPENDENT GRAPHS

Pajor (2009) states that the problem of time-dependency is inherent to public transport networks; trains/buses only operate at certain times and therefore the choice of the quickest route highly depends on the departure time of the journey.

To accommodate for the time-dependency in such networks, the edges are no longer given constant weights. The edge weights are rather assigned with arbitrary functions from some function space. The shortest path in a time dependent model then depends on the departure time of the source vertex. This might then result in shortest paths of different lengths for different departure times or, in general, even a completely different route (Pajor 2009).

Implementation

With time dependent graphs, all edges therein are weighted by periodic time dependent travel time functions $f : \Pi \rightarrow N_0$[12] where Π depicts a set of time points, that is, the minutes of a day (Dibbelt *et al.* 2012).

[12] Natural numbers starting at 0.

Relevant Queries

Dibbelt *et al.* (2012) identified two types of queries: a **time query** and a **profile query.**

A time query has as input the source u ∈ V and the departure time τ. It computes a shortest path tree to every vertex v ∈ V when departing at u at time τ. And in contrast, a profile query computes a shortest path graph from u to all v ∈ V, consisting of shortest paths for all departure times $\tau \in \Pi$.

4.3.2. FINITE STATE AUTOMATA

THE AUTOMATA CONCEPT

In order to understand the concept of automata, it is helpful to envision it (simplistically) as a finite set of states that are connected by a finite number of transitions.

Each of the transitions is labelled by a letter, taken from some finite alphabet. A computation starts at a designated state, the start state or initial state, and it moves from one state to another along the labelled transitions. As it moves, it 'prints' the letter which labels the transition. Thus, during a computation, a string of letters is 'printed' out. Some of the states are also designated as final states, or accepting states. Whenever the computation reaches a final state, the string that was printed so far is said to be accepted by the automaton. Since each computation defines a string, the set of all possible computations defines a set of strings, or in other words, a language. It is said that this language is accepted or generated by the automaton (Wintner 2001).

In order to visualise finite state automata, a graphical depiction is commonly used. The states are usually depicted as circles (i.e. vertices), with the initial state shaded and the final state represented by two concentric circles. Furthermore, the transitions are typically depicted as edges connecting the circles, with the labels placed next to the edges. The collection of all the letters that label the edges in an automaton forms the alphabet. The automaton in Figure 22 (Wintner 2001) has four states: q_0, q_1, q_2 and q_3, and four edges: one labelled c that connects q_0 with q_1; the second labelled b that connects q_1 with q_2; and the other two labelled t and r that both connect q_2 with q_3.

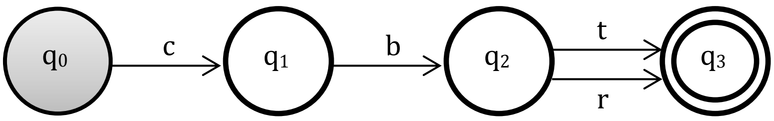


FIGURE 22: FINITE STATE AUTOMATON

MATHEMATICAL PRELIMINARIES

Union (∪): The union of events A and B, denoted as A∪B, is the event that occurs when either A or B, or both, occur (Keller and Warrack 2003).

Intersection (∩): The intersection of events A and B, denoted as A∩B, is the event that occurs when both A and B occur (Keller and Warrack 2003).

Empty set (∅): The set that contains no elements (Stewart 2003).

Subset (⊆): If A is a subset of (or is included in) B, then A⊆B (Wikipedia 2012).

Superset (⊇): If B is a superset of (or includes) A, then B⊇A (Wikipedia 2012).

It should however be noted that, some authors use the symbols ⊂ and ⊃ to indicate 'subset' and 'superset' respectively, instead of the symbols ⊆ and ⊇, but with the same meaning.

AUTOMATA THEORY

Alphabet

An alphabet is a finite, nonempty set of symbols denoted by Σ (Halfeld Ferrari 2007). For example:

- The binary alphabet: Σ = {0, 1}.
- The set of all lower-case letters: Σ = {a, b, ... , z}.
- The set of all ASCII (American Standard Code for Information Interchange) characters.

String

Halfeld Ferrari (2007) defines a string (or sometimes referred to as a word) as a finite sequence of symbols chosen from some alphabet. The length of a string is the number of positions for symbols in the string and is denoted as |w|. As an example, 01101 and 111 are strings from the binary alphabet Σ = {0, 1}, with length of five and three respectively. An empty string has zero occurrences of symbols and is denoted by ∈ with |∈| = 0.

Powers of an Alphabet

The power of an alphabet Σ is expressed by the exponential notation Σ^k : the set of all strings of length k, each of which is in Σ (Halfeld Ferrari 2007). As an example, if Σ = {0, 1}, then:

- Σ^1 = {0, 1}.
- Σ^2 = {00, 01, 10, 11}.
- Σ^3 = {000, 001, 010, 011, 100, 101, 110, 111}.

Kleene Star

The set of all strings over an alphabet Σ can be expressed by the Kleene star ∗ and is denoted as Σ∗. Therefore, $\Sigma* = \Sigma^0 \cup \Sigma^1 \cup \Sigma^2 \cup \Sigma^3$ and so on. As an example: {0, 1}* = {∈, 0, 1, 00, 01, 10, 11, 000, …} (Halfeld Ferrari 2007).

Language

Halfeld Ferrari (2007) defines a language, denoted by L, as a (possibly infinite) set of strings all of which are chosen from some Σ∗. Furthermore, if Σ is an alphabet, and L ⊆ Σ∗, then L is a (formal) language over Σ.

LANGUAGE THEORY

As mentioned previously, the set of all strings over the alphabet Σ is denoted by Σ*. Notice that, independent of what the alphabet is, Σ* is always infinite. Even for an extremely impoverished alphabet that consists of a single letter, say Σ = {a}, Σ* contains the strings $a^0 = \in$, $a^1 = a$, $a^2 = aa$, etc., and in general for every k > 0 the string a^k is in Σ*. It is therefore clear that, since no bound can be imposed on the length of a string in Σ*, it is also impossible to bound the number of the elements in Σ*, and hence Σ* is always infinite.

According to Wintner (2001), a **formal language** over an alphabet Σ is simply a subset of Σ*. And since Σ* is always infinite, the number of its subsets is also infinite. Therefore, in any alphabet Σ, there are infinitely many formal languages over Σ*.

Regular expressions can be defined as a meta-language. That is, a language for specifying formal languages. Wintner (2001) explains the concept of regular expressions as follows:

> "THE SYNTAX OF REGULAR EXPRESSIONS IS FORMALLY DEFINED AND IS RELATIVELY SIMPLE WITH ITS SEMANTICS BEING SETS OF STRINGS IN A FORMAL LANGUAGE. THIS FORMALISM DEFINES REGULAR EXPRESSIONS: FORMAL EXPRESSIONS OVER SOME ALPHABET Σ, AUGMENTED BY SOME SPECIAL CHARACTERS. IT ALSO DEFINES A MAPPING, CALLED DENOTATION, FROM REGULAR EXPRESSIONS TO SETS OF STRINGS OVER Σ. IN OTHER WORDS, EVERY WELL-FORMED REGULAR EXPRESSION DENOTES A SET OF STRINGS, OR A LANGUAGE."

Regular expressions over an alphabet Σ are thus defined as follows (Wintner 2001):

- ∅ is a regular expression.
- ∈ is a regular expression.
- If $a \in \Sigma$ is a letter then *a* is a regular expression.
- If r_1 and r_2 are regular expressions then so are $(r_1 + r_2)$ and $(r_1 . r_2)$.

- If r is a regular expression then so is (r)*.
- Nothing else is a regular expression over Σ.

Regular expressions are useful because they enable one to specify complex languages in a formal and concise way. However, as stated in Wintner (2001), not all languages can be expressed as the denotations of regular expressions. The set of languages, which however can, is called **regular languages**. In order to prove that certain languages are not regular, a well-known technique, the so called Pumping lemma, can be used.

According to Bachmair (2012), the **Pumping lemma** states that all regular languages have a special property. If it can be shown that a language L does not have this property, it is guaranteed that L is not regular. However, the Pumping lemma does not state that only regular languages have this property. Hence, the property used to prove that a language L is not regular, does not ensure that language L is regular. The Pumping lemma is defined as follows (Bachmair 2012).

Theorem 1: The Pumping Lemma

If L is a regular language, then there is a pumping length ρ such that:

- *If s is any string in L of length at least ρ*
- *Then s may be divided into three pieces, s = xyz, satisfying the following conditions:*

  i. *for each* $i \geq 0,\ x y^i z \in L$
  ii. $|y| > 0$
  iii. $|xy| \leq \rho$

If one now assumes that each element of language L satisfies the three conditions (i.e. i-iii) stated in the Pumping lemma, then a finite state automata that recognises L, that is, L is regular, can easily be constructed.

DETERMINISTIC FINITE STATE AUTOMATON

DEFINITION

The idea of Deterministic Finite Automaton (DFA) is that on each input there is one and only one state to which the automaton can transition to from its current state. Halfeld Ferrari (2007) defines the DFA A as follows.

Definition 1: DFA

- *A finite set of states Q.*
- *A finite set of input symbols Σ, called the alphabet.*
- *A transition function δ that takes as arguments a state Q and an input symbol Σ and returns a state: Q x Σ → p(Q). If q is a state and b is a symbol, then δ(q, b) is a state p. That is, in the graph that represents the automaton, this would be shown as an edge from q to p labelled b.*
- *A start state q_0, which is one of the states in Q ($q_0 \in Q$).*
- *A set of final or accepting states F with $F \subseteq Q$.*

A DFA *A* is thus a 5-tuple (i.e. a sequence of five elements) denoted as *A* = (Q, Σ, δ, q_0, F). The finite state automaton in Figure 22 (Wintner 2001) can be formally written as: Q = {q_0, q_1, q_2, q_3}, Σ = {c, b, t, r}, δ = {[q_0, c, q_1], [q_1, b, q_2], [q_2, t, q_3], [q_2, r, q_3]}, q_0 = {q_0}, and F = {q_3}.

EXTENDED TRANSITION FUNCTION

The extended transition function of a DFA, denoted by *δ*, is a function that takes a state q and a string ω and returns a state p; the state that the automaton reaches when starting in state q and processing the sequence of inputs in the string ω. This is denoted by *δ*(q, ω) = p (Halfeld Ferrari 2007). The extended transition function *δ* thus extends the relation δ from arcs to strings. In Figure 22 (Wintner 2001), *δ* = {[q_0, ∈, q_0], [q_1, ∈, q_1], [q_2, ∈, q_2], [q_3, ∈, q_3], [q_0, c, q_1], [q_1, b, q_2], [q_2, t, q_3], [q_2, r, q_3], [q_0, cb, q_2], [q_1, bt, q_3], [q_1, br, q_3], [q_0, cbt, q_3], [q_0, cbr, q_3]}. Note that the middle element of each triple may be a **string,** rather than just a letter as was the case with δ.

LANGUAGE

The language of a DFA *A* = (Q, Σ, δ, q_0, F), denoted L(A), is defined by (Halfeld Ferrari 2007):

L(A) = {ω | *δ*(q_0, ω) is in F}

The language of A is thus the set of strings ω that take the start state q_0 to one of the accepting states.

NONDETERMINISTIC FINITE STATE AUTOMATON

DEFINITION

In Nondeterministic Finite Automaton (NFA), the automaton can be in several states at once. Therefore, the main difference between the DFA and the NFA is related to the type of transition function δ needed. For a NFA, δ is a function that takes a state and input symbol as arguments (like the DFA transition function), but returns a set of zero or more states, rather than returning exactly one state, as the DFA does (Halfeld Ferrari 2007).

Halfeld Ferrari (2007) defines a NFA as a 5-tuple A = (Q, Σ, δ, q_0, F).

Definition 2: NFA

- *Q is a finite set of states.*
- *Σ is a finite set of input symbols, called the alphabet.*
- *δ is the transition function that takes a state in Q and an input symbol in Σ as arguments, and returns a subset of Q.*
- *$q_0 \in Q$ is the start state.*
- *F is the set of final or accepting states with $F \subseteq Q$.*

EXTENDED TRANSITION FUNCTION

The extended transition function of a NFA, denoted by δ, is a function that takes a state q and a string ω and returns a subset of Q. To explain this concept, consider the following:

- Suppose ω is a string of the form xc; that is c is the last symbol of ω, and x is the string consisting of all but the last symbol.
- Also suppose that $\delta(q, x) = \{p_1, p_2, \ldots, p_k\}$.
- And Let $_{i=1}^{k}\delta(p_i, c) = \{r_1, r_2, \ldots, r_m\}$.
- Then $\delta(q, \omega) = \{r_1, r_2, \ldots, r_m\}$.

One therefore computes $\delta(q,\omega)$ by first computing $\delta(q, x)$ and by then following **any** transition from **any** of the states that are labelled c.

LANGUAGE

The language of a NFA A = (Q, Σ, δ, q_0, F), denoted L(A) is defined by:

$L(A) = \{\omega \mid \delta(q_0, \omega) \cap F \neq \emptyset\}$

The language of A is the set of strings $\omega \in \Sigma^*$ such that $\delta(q_0, \omega)$ contains at least one accepting state (Halfeld Ferrari 2007).

DFA AND NFA

According to Halfeld Ferrari (2007), every language that can be described by some NFA can also be described by some DFA. Furthermore, the DFA has, in practice, about as many states as the NFA, although it has more transitions. And in the worst case, the smallest DFA can have 2^n states, for a smallest NFA with n states.

For the application required herein, that is, modelling the multi-dimensional nature (due to the complex choice behaviour in executing multiple activities) of multimodal journeys, a NFA should be utilised.

4.4. MODELLING THE MULTIMODAL SUPERNETWORK

4.4.1. INTRODUCTION

According to Zhang, J. *et al.* (2011), the multimodal transport network should be modelled from a functional point of view. That is, the individual networks should be viewed separately as either a Public Transport Network (PTN) or a Private Vehicle Network (PVN). This viewpoint is deemed suitable, because it allows for the modelling of a multimodal supernetwork. That is, the concatenation of the appropriate transport networks into a multimodal network, interconnected by transfer links.

PRE-MODELLING CONSIDERATIONS

The two most important pre-modelling considerations are the time- and monetary weight attributes.

Firstly, a decision regarding the time attributes, for the modelling of the PTN and the PVN, needs to be made. As mentioned previously, the PTN is generally modelled as a time dependent-, and the PVN as a time independent network.

Secondly, the manner in which the monetary weight is to be calculated needs to be decided. As stated in Zhang, J. *et al.* (2011), the total monetary weight of a journey is commonly calculated by accumulating the weight (distance, time or cost) consumed in each segment of the journey. Another method is to use a Generalised-Cost (GC) measure. As is mentioned previously, a GC approach allows the users to attach differential importance to various segments of his/her journey. Other methods include conjoint analysis (stated choice experiments) or estimating the weights based on previous observations of the actual travel choices of a sample of individuals.

SOLVING FOR THE OPTIMUM MULTIMODAL JOURNEY

According to Zhang, J. *et al.* (2011), the algorithms needed in modelling the multimodal supernetwork are <u>two-folded</u>:

1. An algorithm for compiling the multimodal supernetwork, based on data about the road network and the public transport services, is needed.
2. A routing algorithm that is able to find multimodal routes as shortest paths through the supernetwork is needed.

An overview of the overall procedural steps required follows:

- Based on the time attributes (i.e. time-dependency or -independency) decided, develop the individual networks for the PTN and the PVN.

- Integrate the individual networks into a single multimodal transport supernetwork. (ALGORTIHM 1)
- Based on the monetary attributes (i.e. distance, time or cost) decided, determine the shortest path in the multimodal transport supernetwork. (ALGORITHM 2)

4.4.2. THE GRAPH MODELS FOR THE INDIVIDUAL NETWORKS

THE PUBLIC TRANSPORT NETWORK

Due to any Public Transport Network's (PTNs) inherent dependency on time, that is, its dependence on timetables, it is proposed that **travel time** be used as the weight metric in the PTN.

TIMETABLES

According to Pyrga *et al.* (2008), a timetable consists of data concerning: stops/stations, public transport mode options, connecting stops/stations, departure- and arrival times at stops/ stations, and the days of the week. A more formal definition of a timetable follows (Pyrga *et al.* 2008).

Definition 3: Public Transport Timetable

A timetable is a tuple $(C, B, \mathcal{Z}, \Pi)$ where B is a set of stops/stations, $\mathcal{Z}$ is a set of public transport modes (either train, bus or IRPT), Π is the periodicity of the timetable and C a set of elementary connections. The elements of an elementary connection from C is defined by a tuple $c = (Z, S_1, S_2, \tau_1, \tau_2)$ and is interpreted as a public transport mode $Z \in \mathcal{Z}$ going from stop/station $S_1 \in B$ to the immediately next stop/station $S_2 \in B$, departing at S_1 at time $\tau_1 < \Pi$ and arriving at S_2 at $\tau_2 < \Pi$.

With this definition, there are thus no stops in-between S_1 and S_2. As a result, it is evident that a route (or thus a journey) will consist of a sequence of multiple elementary connections relating to the timetable. This is denoted by: $P = (c_1, c_2, \ldots, c_k)$ for each elementary connection c_i, $1 \leq i \leq k$. According to Pyrga *et al.* (2008), such a sequence P is called a consistent connection from stop/station $A = S_1(c_1)$ to stop/station $B = S_2(c_k)$ if it respects the transfer times at stops/stations and thus fulfils the following consistency conditions: 1) the departure station of c_{i+1} is the arrival station of c_i, and 2) the time values $dep_i(P)$ and $arr_i(P)$ correspond to the time values τ_1 and τ_2, respectively.

Pyrga *et al.* (2008) furthermore state that the departure- and arrival time τ_1 and τ_2 of an elementary connection $c \in C$ within a day should be denoted by integers in the interval [0, 1439]. The number 1 439 represents the time in minutes after midnight (i.e. 23x60 + 59). And due to the periodicity of the timetables, that is, that none of the considered public transport modes (i.e. train, bus or IRPT) operate after midnight, the arrival time τ_2 will always be greater than the departure time τ_1. Consequently, the length of the elementary connection, i.e. length(c), can simply be determined by the cycle difference: $\tau_2 - \tau_1$.

According to Pyrga *et al.* (2008), this timetable information is used in combination with a sequence of queries, where a query defines a set of valid connections and an optimisation criterion (or criteria) on that set of connections, to address the problem in finding the optimal connection (or a set of optimal connections), with respect to the specific criterion (or criteria).

PUBLIC TRANSPORT GRAPH MODELS

The three main PTN graph models that will be considered herein, are: 1) the condensed model, 2) the time expanded model and 3) the time dependent model.

The Condensed Model

According to Pajor (2009), a (time independent) condensed model is the most basic approach to model the PTN. In this model there is for every stop/station S ∈ B of the timetable, exactly one vertex v ∈ V in the graph. An edge e = (u, v) is introduced, if and only if, at least one elementary connection in the timetable, that goes from u to v, exists. The weight of this edge, w(e), is calculated as the minimum travel time of all connections going from u to v. Refer to Equation 1 (Pajor 2009).

EQUATION 1: THE EDGE WEIGHT IN THE CONDENSED MODEL

$$\mathrm{w(e)} = \min_{\substack{c \in C \\ u=S_1\ c \\ v=S_2(c)}} \Delta\left(\tau_1(c), \tau_2(c)\right)$$

Pajor (2009) states that, even though the condensed model yields a small graph size and can also represent the structure of the PTN adequately, is not useful for exact shortest path queries since it does not account for the departure- and arrival times between two stops/stations in the timetable. Therefore, for computing exact travel times, this model cannot be used.

The Time Expanded Model

To address the shortcoming of the condensed model, while still being able to use a time independent approach, the time expanded model was developed. According to Pajor (2009), there are two versions of this model: 1) the simple time expanded model and 2) the realistic time expanded model. The simple version is a direct mapping from an itinerary with shortest path queries yielding correct results. However, it does not account for realistic transfers. For example, when transferring at a stop/station S during a journey, there is most likely a minimum transfer time involved. To incorporate this aspect, the simple version has been enhanced to the realistic model. An explanation of each follows.

1. The Simple Time Expanded Model

In this version, the vertices in the graph no longer correspond to stops/stations (as was the case with the condensed model) in the timetable, but rather to events. That is, there is a vertex for every time event (i.e. departure or arrival) at each stop/station. Therefore, for each elementary connection c = (Z, S_1, S_2, τ_1, τ_2), there is now a departure event Z at stop/station S_1 at time τ_1 and an arrival event Z at stop/station S_2 at time τ_2 (Pajor 2009). In order to keep track of which stop/station a vertex belongs, each vertex is assigned its stop/station S and also its timestamp τ of when the event occurs. Furthermore, each elementary connection also has two types of edges. Firstly, a set of edges that connects a departure vertex belonging to stop/station S_1 and associated with time τ_1, to an arrival vertex belonging to stop/station S_2 and associated with time τ_2, needs to be defined. (In other words, the endpoints of the mode edges induce the set of vertices in the graph.) This edge weight is set to be the travel time. Refer to Equation 2 (Pajor 2009).

EQUATION 2: THE WEIGHT OF EDGE TYPE 1 IN THE SIMPLE TIME EXPANDED MODEL

$$w(e)_{type\ 1} = \Delta\ (\tau_1(c), \tau_2\ (c))$$

In order to allow transfers, the vertices that belong to the same stop/station S, need to be sorted in ascending order with regard to their timestamps. This results in the second edge type: for two subsequent vertices, v_i and $v_{i+1,}$ that have timestamps τ_i and τ_{i+1}, an internal stop/station edge e = (v_i, v_{i+1}) needs to be introduced. The weight of this edge is calculated as the difference in the corresponding timestamps and thus represents the waiting time within a stop/station. Refer to Equation 3 (Pajor 2009).

EQUATION 3: THE WEIGHT OF EDGE TYPE 2 IN THE SIMPLE TIME EXPANDED MODEL

$$w(e)_{type\ 2} = \Delta\ (\tau_i, \tau_{i+1})$$

2. The Realistic Time Expanded Model

In order to cope with realistic transfers, this model's elementary connection is extended to assign each stop/station in the network, a transfer time. Pyrga *et al.* (2008) state that, for each stop/station S $\in$ B, a copy of all the departure- and arrival events at the stop/station, needs to be kept. These are referred to as transfer events. And while the arrival vertices still represent arrival events of the timetable, the departure events are now modelled by a pair of vertices consisting of a transfer- and a departure vertex (Pajor 2009). Refer to Figure 23 (Pyrga *et al.* 2008).

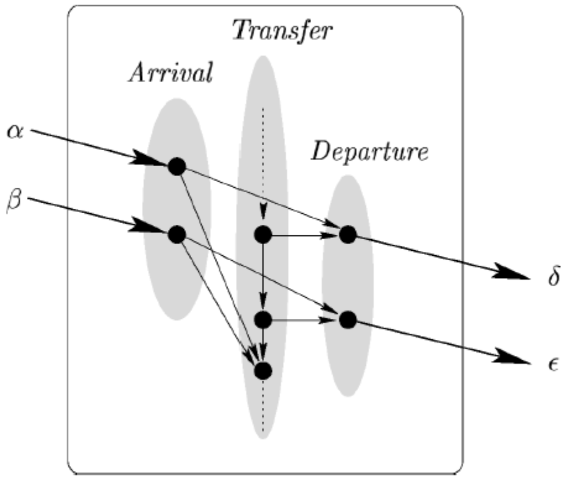


FIGURE 23: THE REALISTIC TIME EXPANDED MODEL

> Furthermore, according to Pyrga *et al.* (2008), a set of edges, between the transfer events, needs to be introduced. That is, for every arrival event, there should be one edge to the first transfer event with the time value greater than or equal to the time of the arrival event plus the minimum time needed to change transport mode at the corresponding stop/station. Then there is also a second edge type: one from the arrival event to the departure event of the same transport mode. This edge is inserted, if and only if, the respective transport mode departs from the corresponding stop/station; otherwise there is no second edge. The weights of these edges are computed analogously to that stated in the simple version of this model.

According to Pajor (2009), the time expanded model 'rolls out' the time dependencies of a timetable and allows for exact shortest path queries with regard to the Earliest Arrival Problem (discussed in Section 4.6.1). That is, for a given departure time τ at some source stop/station S, the source vertex is determined to be the earliest stop/station- or transfer vertex (depending on the version of the model used) with timestamp(S) $\geq \tau$. Furthermore, Pajor (2009), states that, while the greatest advantage of the time expanded model is its easy adaption of the standard Dijkstra query algorithm (discussed in Section 4.6.1), there are two main disadvantages. Firstly, since the arrival time is unknown, the target (aka sink) vertex is thus also not known in advance of the query execution. And even though this does not affect the correctness of the algorithm, it does however make the use of bi-directional speed-up technique (discussed in Section 4.7.1) difficult. Secondly, with this model, the size of the graph gets extremely large. As a result, it consumes a lot of memory and also leads to a very large search space for Dijkstra's algorithm.

The Time Dependent Model

The time dependent model overcomes all the shortcomings of the time expanded model, but with the penalty of introducing time-dependency in the graph. According to Pajor (2009), there are two versions of this model: 1) the simple time dependent model and 2) the realistic time dependent model. The simple version again does not incorporate the minimum transfer time criterion; whereas the realistic version, deals with this issue by again enhancing the simple model. An explanation of each follows.

1. The Simple Time Dependent Model

As stated in Pajor (2009), this version is an immediate augmentation of the condensed model. That is, the vertex set is again the set of stops/stations and a connection edge between two vertices u and v is inserted, if and only if, there is at least one connection from u to v in the timetable. However, instead of using lower bounds as edge weights, with this model, these edges become time dependent.

For the edge function type, a piecewise linear function f is used. A piecewise linear function can be defined as follows (Pajor 2009).

Definition 4: Piecewise Linear Function

A periodic function $f\colon \mathbb{R}_0^+ \rightarrow \mathbb{R}_0^+$ *is called piecewise linear if it consists of a finite number of segments of linear functions. Now, if f is a piecewise linear function, then f can be described by a finite set* $\mathcal{B}$ *of interpolation points, where each interpolation point* $p_i \in \mathcal{B}$ *consists of a departure time* τ_i *and an associated function value* $f(\tau_i)$*. This function value, for an arbitrary time* τ*, can then be computed by interpolation.*

For each elementary connection c = $(Z, S_1, S_2, \tau_1, \tau_2)$ in the timetable, an interpolation point p = $(\tau_1, \Delta(\tau_1, \tau_2))$, that belongs to the edge connecting S_1 and S_2, needs to be added to the piecewise linear function f. According to Pajor (2009), this can be seen as a correspondence of interpolation points to departure events on the particular edge in the network. Thus, if one evaluates the function f at one of its interpolation points τ_i, the value of $f(\tau_i)$ results precisely in the travel time of the i^{th} transport mode on that segment. If one, on the other hand, evaluates the edge at an earlier point $\tau < \tau_i$, the traveller will have to wait at S_1 for the next transport mode to depart. Therefore, if one evaluates the function f at some arbitrary time point τ, the nearest interpolation point τ_i in the future is used to interpolate the edge weight $f(\tau)$. Refer to Equation 4 (Pajor 2009).

EQUATION 4: THE EDGE WEIGHT IN THE SIMPLE TIME DEPENDENT MODEL

$$f(\tau) = f(\tau_i) + (\tau_i - \tau)$$

As can be seen in Equation 4 (Pajor 2009), the travel time function along an edge is thus composed of the travel time $f(\tau_i)$ and the waiting time $(\tau_i - \tau)$.

A comparison of the simple time expanded- (top) and the simple time dependent model (bottom) can be seen in Figure 24 (Pyrga *et al.* 2008).

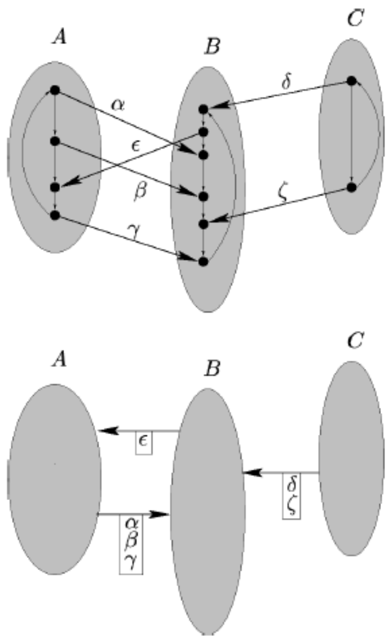


FIGURE 24: A COMPARISON OF THE TWO SIMPLE MODELS

In Figure 24 (Pyrga *et al.* 2008), A, B and C depict three stops/stations, and there are three transport modes that connect A with B (elementary connections α, β and γ), one transport mode from C to A via B (δ, ϵ), and one transport mode from C to B (ζ).

2. The Realistic Time Dependent Model

In this model, the timetable is again extended to assign each stop/station a (constant) transfer time. (This model can also be generalised further to account for variable transfer times. However, this it will not be considered in this research project.)

Just as in the simple version of the time dependent model, the vertex set is again a set of stops/station. However, here they are not directly interconnected as in the simple model. In this version of the time dependent model, an additional vertex type, called route vertices, is inserted. According to Pajor (2009), the idea is to have the train/bus/IRPT that take the same route, go through subsequent route vertices. These route vertices are then connected to their respective stop/station vertices with the proper weight matching their transfer times. In order to accomplish this, the set of public transport modes Z needs to be divided into train/bus/IRPT routes, denoted by $\mathcal{R}$. Each train/bus/IRPT route $R \in \mathcal{R}$ is then a maximal subset of $\mathcal{Z}$ containing only trains/buses/IRPT following the exact same sequence of stops/stations. The sequence of stops/stations belonging to some train/bus/IRPT route $R \in \mathcal{R}$ can be denoted as $[S_1, S_2, \ldots, S_k]$. Then, according to Pajor (2009), for each stop/station $S_i \in R$, a route vertex r_i

needs to be inserted into the graph. These subsequent route vertices should then be connected with time dependent edges: e = (r_i, r_{i+1}), with the interpolation points of the function f_e at e added analogously to that of the simple version of this model. Furthermore, in order to allow intramodal transfers between different routes, additional transfer edges also need to be introduced. That is, for some station S, consider each of the route vertices r belonging to S, and insert two additional edges. The first edge (r, S) is from the route vertex to the stop/station vertex with a constant weight 0. This represents disembarking a train/bus/IRPT, which is, according to Pajor (2009), not weighted with any time. The second edge (S, r) represents boarding the train/bus/IRPT. The weight of this edge is set to transfer(S) – the minimum (constant) transfer time at a stop/station.

According to Pajor (2009), the time dependent model allows, in a time dependent fashion, exact shortest path queries for the Earliest Arrival Problem. And for both the simple- and the realistic version, with constant transfer times, the source- and target (aka sink) vertex are known in advance. These are simply the stop/station vertices corresponding to the source- and target stop/station of the query. Furthermore, Pajor (2009) states that, when using a time dependent model, the graph size is much smaller than that of the time expanded model. The simple approach of this model has the same graph size as the condensed model (which is very small), whereas the graph size of the realistic approach of this model increases, approximately, by a factor of five compared to the simple model (which is still much smaller than the time expanded realistic model). However, these advantages come with a penalty. That is, the graph is no longer time independent. This not only requires an augmentation of the Dijkstra query algorithm, but also additional memory to store the piecewise linear functions.

PTN MODELS

It is proposed herein that the Public Transport Network (PTN) be modelled as a time dependent model. More specifically: the realistic time dependent model with constant transfer times. According to Pajor (2009), the advantages of this model (e.g. the smaller graph size) outweigh its disadvantages, since query times are smaller. Therefore, according to Dibbelt *et al.* (2012), the PTN should consist of station/stop vertices connected to route vertices, with the transport modes modelled between these route vertices via time dependent edges.

Furthermore, in order to model user preferences based on finite state automata (i.e. NFA) and language theory (i.e. regular language), it is recommended that the edges in the PTN be labelled with rail (i.e. t), bus (i.e. b) and IRPT (i.e. m) respectively. Consequently, it is proposed that the PTN, apart from having vertices and edges, also comprises two additional functions. A cost function: c for the travel time and a label function: ℓ for the transit mode (i.e. t, b and m). That is, G = (V, E, c, ℓ).

THE PRIVATE VEHICLE NETWORK

As mentioned previously, the absence of time-dependency in a road network still yields useful queries. Furthermore, according to the relating research, the recognised way to build a road graph is to use time independent modelling. Consequently, even though the Private Vehicle Network (PVN) is influenced by the time of travel (i.e. congestion imposed in peak hours), it is proposed herein that the PVN be modelled as a time independent graph. That is, that the weight of each edge be given a constant value, such as: travel time, geographical distance or any other appropriate metric.

THE ROAD NETWORK MODEL

Dibbelt *et al.* (2012) state that, in a time independent road network, the intersections should be modelled as vertices and the edges, depicting road segments, should connect these vertices. An edge $e \in E$ between two intersections $u, v \in V$ should only be inserted, if and only if, a road segment from u to v, in the road network, exists. Note that, if in reality the road between u and v is a two-way road, then two edges (u, v) and (v, u) should be inserted into the graph.

In order to be consistent with the PTN, it is recommended that the road network also be weighted by the average **travel time** of the road segment. Thus, the edge weights in the road network should represent the average travel time on each road segment. The average travel time can be calculated by using the geographical length of the road segment and the average traffic speed thereon.

In multimodal routing, it is a realistic assumption that a traveller does not necessarily have a car available to him/her everywhere along his/her journey. Therefore, Pajor (2009) states that, in order to still be able to make point to point queries in the road network, some sort of foot edges need to be incorporated into the graph. From a theoretical point of view, one simply needs to insert an additional edge between two intersections u and v, if the road segment is available to pedestrians. The edge weight of the foot edge can then be computed by taking the geographical length of the road segment and assuming an average walking speed of 4.5 km/h.

In essence, the PVN thus constitutes a foot (pedestrian) network. Therefore, based on finite state automata (i.e. NFA) and language theory (i.e. regular language), it is recommended that the edges in the PVN be either labelled with car for roads (i.e. c) or foot for pedestrians (i.e. f). Consequently, it is proposed that the PVN, apart from having vertices and edges, also comprises two additional functions: 1) a cost function: c for the travel time and 2) a label function: ℓ for the transit mode (i.e. c or f). That is, $G = (V, E, c, \ell)$.

A HOLISTIC VIEW OF THE PVN AND THE PTN

From the previous discussion, it is clear that the basic elements of the Private Vehicle Network (PVN) and the Public Transport Network (PTN) are vertices and edges. The vertices and edges, corresponding to both the PTN and the PVN can, in an overall manner, be classified as follows (Zhang, J. *et al.* 2011).

- Physical vertices are X and Y coordinates that either denote intersections in the PVN or the location of stops/stations in the PTN.
- Event vertices are only applicable to the PTN and represent arrivals or departures at stops/stations. They are characterised by event type (i.e. arrival or departure), event time and service related factors (e.g. routes, stop sequence, etc.). If the event type is arrival, then the direction is from the event vertex to the physical vertex, and if the event type is departure, the direction is reversed. Furthermore, all event vertices are ordered in the way that a higher-level vertex refers to an earlier event.
- Transfer vertices are used to depict the intercept/interchange points between the individual networks.
- Route vertices are only applicable to the PTN and are used to connect the physical vertices that follow the same route.
- Physical edges connect physical vertices and they can depict distance, time, speed, monetary cost, emission, quality or general cost.
- Trip sequence edges are used to connect event vertices between stops/stations with the directions of these edges being from an earlier event to a later event; representing either waiting- or transferring time.
- Transfer edges connect transfer vertices and are added based on their closeness to one another. They can either be within the same mode (e.g. transfer from one train to another) or between different modes (e.g. transfer from bus to train). Furthermore, since walking is always involved in traversing, all transfer links should be connected to the foot (pedestrian) network.

CALCULATING TRAVEL TIME AS THE WEIGHT METRIC

If travel time is used as the edge weight, with the vertices and edges categorised as defined above, the following four situations for calculating the weight metric are distinguished in Zhang, J. *et al.* (2011):

1. If the source vertex is a physical vertex and the target (aka sink) vertex is also a physical vertex, then the weight of the edge equals the length of the link divided by the speed.

2. If the source vertex is a physical vertex and the target vertex is an event vertex (i.e. arrival), two cases exist. If the timestamp of the event vertex is later than the current time at the physical vertex, then the time on the edge equals the difference, else it equals positive infinity (i.e. the vertex cannot be reached).
3. If the source vertex is an event vertex (i.e. departure) and the target vertex is a physical vertex, then the time on the edge equals the length of the link divided by the speed.
4. If the source vertex is an event vertex (i.e. departure) and the target vertex is also an event vertex (i.e. arrival), then time on the edge equals the difference between their timestamps (i.e. waiting time).

4.5. THE MULTOMODAL SUPERNETWORK ALGORITHM FOR COMBINING THE INDIVIDUAL NETWORKS

In order to combine the individual graphs, link (transfer) edges need to be inserted between pairs of vertices of different networks that are located geographically close to each other. This gives rise to the Nearest Neighbour Problem.

4.5.1. THE NEAREST NEIGHBOUR PROBLEM

Let $\mathbb{R}^n$ be the n-dimensional vector space over $\mathbb{R}$[13] and $P \subset \mathbb{R}^n$ a finite set of vectors, with the set P referred to as candidate points. Furthermore, let $d: \mathbb{R} \times \mathbb{R} \rightarrow \mathbb{R}$ be a metric on $\mathbb{R}^n$. The Nearest Neighbour Problem is then defined as follows (Pajor 2009).

Definition 5: The Nearest Neighbour Problem

Given a metric space ($\mathbb{R}^n$, d), a set of candidate points P *on* $\mathbb{R}^n$ *and a set Q of query points on* $\mathbb{R}^n$*, one is asked for a map* $f : Q \rightarrow \mathrm{P}$ *with the property in Equation 5.*

EQUATION 5: THE NEAREST NEIGHBOUR PROBLEM

$$f(q) = \mathrm{p} \Leftrightarrow \forall p' \in \mathrm{P} : p \neq \mathrm{p}' \Rightarrow d(p',q) \geq d(p,q)$$

Equation 5 (Pajor 2009) thus aims in finding the nearest candidate point p ∈ P, for each query point q ∈ Q, with regards to the metric d.

In Pajor (2009), two algorithms for solving the Nearest Neighbour Problem are identified. The first is a linear search method; and the second a clever data structure, called k-d trees (k-dimensional trees).

[13] Real number.

LINEAR SEARCH

According to Pajor (2009), the simplest approach to solving the Nearest Neighbour Problem, is the linear search method. With this approach, each query point $q \in Q$ is considered and scanned in order to obtain the list of candidate points P, from which the point having the minimum distance to q, can be determined. In essence, this requires the distance to be computed between each pair $(q, p) \in Q \times P$ of points.

The linear search method thus has a time complexity of $\Theta(|P|)$ per query and a running time of $\Theta(|Q|.|P|)$. Pajor (2009) accordingly states that, even though the implementation of this algorithm is straightforward, it is not feasible for large sets of P and Q.

K-D TREES

Pajor (2009) defines k-d-trees as a data structure that is specifically designed for geometric search algorithms. The algorithm operates in two phases. Firstly, a k-d tree is created with all candidate points P. Secondly, for each query point $q \in Q$, a query on the data structure is stated which yields the nearest neighbour of q.

K-d trees are thus basically an augmentation of binary search trees to k dimensions, which then contain k-dimensional vectors, and can accordingly be answered in average logarithmic time. Consequently, since each query can be answered in an average time of $\Theta(\log |P|)$, the running time of the algorithm (in comparison to the linear search method) reduces to $\Theta(|Q|\log|P|)$ (Pajor 2009).

4.5.2. THE MERGE- AND LINK OPERATIONS

For the purpose of this research project, it is assumed that, both the Private Vehicle Network (PVN) and the Public Transport Network (PTN) are equipped with functions $coord_x : V \rightarrow \mathbb{R}$ and $coord_y : V \rightarrow \mathbb{R}$, which map every vertex to its geographical location given in x- and y coordinates represented as latitude and longitude values.

Pajor (2009) states that the process of combining the networks can be described as an application of two operations: the merge- and the link operation. While the merge operation essentially unifies the vertex- and edge sets of the multiple individual graphs; the link operation inserts the appropriate link edges (i.e. transfer edges) needed to connect the individual networks together into a multimodal supernetwork.

MERGING THE INDIVIDUAL NETWORKS

When combining multiple unimodal graphs, the first step is to apply the merge operation on all the input graphs.

Pajor (2009) defines merging as follows: given a number of unimodal graphs $G_1, \ldots, G_n$, each with vertex- and edge sets $G_i = (V_i, E_i)$, the merge operation yields a multimodal graph **G = (V, E)**[14], where the vertex- and edge sets are simply the union of the vertex- and edge sets of the individual input graphs. Thus $\mathbf{V} = V_1 \cup_{\ldots} \cup V_n$ and $\mathbf{E} = E_1 \cup_{\ldots} \cup E_n$. And in order to still be able to distinguish between different vertex types in the resulting multimodal graph, a function label (that assigns each vertex/edge a label) is introduced: $V \cup E \rightarrow \mathcal{L}vertex \cup \mathcal{L}edge$. Pajor (2009) further states that another flag, d_{ij}, also needs to be introduced. The flag d_{ij} indicates whether a certain vertex $v \in \mathbf{V}$ can be used as a source respective target vertex for Dijkstra's algorithm (or any other shortest path algorithm). In the PVN, every vertex is a legitimate source- or target vertex. However, in the PTN, only the stop/station vertices (i.e. physical vertices) are used as vertices to support shortest path queries. Therefore, in the PTN, the d_{ij} flag is set to false for all the other vertices. Besides this function of the d_{ij}, the flag also has an important role in the link operation. That is, the link edges are only inserted between vertices that have the d_{ij} flag set to true.

After using the merge operation to obtain a multimodal graph **G**, the next step is to repeatedly apply the link operation. This operation links two sub-graphs of different type in **G** together by inserting link edges (i.e. transfer edges).

LINKING THE INDIVIDUAL NETWORKS

According to Pajor (2009), the link operation involves linking the different networks contained in **G** by inserting appropriate link edges. These link edges indicate where transferring between the networks are possible. It should however be noted that one execution of the link operation, only links two networks together. Therefore, in order to obtain a multimodal network consisting of more than two networks, the link operation has to be applied multiple times.

In Pajor (2009), the following example is given. Assume that one wants to obtain a multimodal graph consisting of a road-, a railway- and flight network. This procedure would require three link operations: 1) linking the railway network to the road network, 2) linking the flight network to the railway network and also 3) linking the flight network to the road network. Refer to Figure 25 (Pajor 2009).

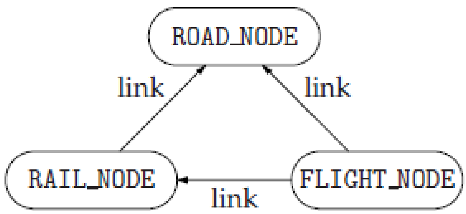


FIGURE 25: AN EXAMPLE OF THE LINK OPERATION

[14] In order to make multimodal graphs better distinguishable from unimodal graphs, it is typed with bold letters.

If one then, for example, wants to link the railway network to the road network, the goal is to find, for each station in the railway network, a vertex in the road network that is as close as possible to the station vertex considered, and then, to link them. (The finding of the nearest road vertex is an exact instance of the Nearest Neighbour Problem.) The set of candidate vertices P thus consists of all nodes $v \in \mathbf{V}$ with $\mathcal{L}$vertex(v) = road, and the set of query points Q is the set of all station vertices, thus $v \in \mathbf{V}$ with $\mathcal{L}$vertex(v) = rail and $d_{ij}(v)$ = true.

A more general definition of the link operation, given in Pajor (2009), follows: if one wants to link a network of type T_1 to a network of type T_2, one needs to define Q = {v ∈ **V** | $\mathcal{L}$vertex(v) = T_1 and $d_{ij}(v)$ = true} and equivalently P = {v ∈ **V** | $\mathcal{L}$vertex(v) = T_2 and $d_{ij}(v)$ = true}. Now, when solving the two dimensional Nearest Neighbour Problem on (P, Q, d), with an appropriate weight metric d, it yields for each vertex $q \in Q$ of type T_1, the closest vertex p of type T_2 from P. However, since it is possible that there might be no connection between two vertices in the real world (e.g. not every bus stop has a railway station close by), the pair (q, p) needs to be omitted in the calculation if $d(q, p) > d_{max}$ (where d_{max} is a threshold parameter indicating the maximum distance allowable for which links should still be inserted). Lastly, two edges $e_1 = (p, q)$ and $e_2 = (q, p)$ also need to be inserted into the graph. Both of them have a weight d(p,q)/s, where s denotes the average walking speed of a pedestrian. And as mentioned previously, a walking speed of 4.5 km/h can be assumed.

It should be noted that, according to Pajor (2009), the link operation is not symmetrical. Therefore, if one links the railway network to the road network, it implies that, for each station vertex, a link to the nearest road vertex, is inserted. However, if one tries to link the road network to the railway network, one would end up inserting link edges for each vertex in the road network (i.e. each intersection) to the nearest railway station. Not only is this most likely not what was wanted, but it may also result in an (unnecessary) extensive computation. For that reason, the manner in which the networks are connected (i.e. the direction of the arrows - as shown in Figure 25 (Pajor 2009)) are important.

DISTANCE METRICS

In describing the link operation, no specific weight metric d for the nearest neighbour search was defined. Pajor (2009) states that, because the x- and y coordinates are in a geographical format (i.e. latitude and longitude), using the Euclidean Method (discussed in Section 5.3.1) to compute $d(p_1, p_2)$ will result in insufficient answers. Furthermore, the error in distance will increase the more p_1 and p_2 are positioned apart. Pajor (2009) therefore proposes that the geodetic distances (on a solid resembling the form of earth) be used: e.g. the GRS80-ellipsoid[15]. However, while using the GRS80-ellipsoid as the metric in the Nearest Neighbour Search would yield the most accurate

[15] Geodetic Reference System 1980 (also used by Global Positioning Systems).

results, the implementation of the k-d-trees only supports the Euclidean metric. Nevertheless, Pajor (2009) states that, because for small distances the error using the Euclidean metric is relatively insignificant, one can still retrieve good estimates of the m nearest neighbours for a query point q. Consequently, Pajor (2009) proposes that a cascaded approach be used. That is, for each query point q, the m nearest neighbours P_q (according to the Euclidean metric using k-d-trees) are computed, with the best option from P_q selected by applying the linear search algorithm on Q' = {q} and P_q by using the GRS80-metric. According to Pajor (2009), for small values of m (e.g. $m \leq 100$), this produces results of high quality, while still having a reasonably fast running time.

4.6. THE MULTIMODAL ROUTING ALGORITHM FOR DETERMINING THE SHORTEST PATHS IN A SUPERNETWORK

As mentioned previously, when planning a journey from a start- to a destination point, there might be diverse criteria as to how the best route should be calculated: e.g. the travel time, the cost, or the number of transfers. The usage of multiple criteria for optimisation in route planning is called multi-criteria search and is not covered herein. This research project is restricted to single-criteria search algorithms; more specifically, the optimisation of travel time alone.

4.6.1. (UNIMODAL) ROUTING ALGORITHMS

THE EARLIEST ARRIVAL PROBLEM

According to Pajor (2009), the Earliest Arrival Problem considers all possible routes in the network, starting at time τ, from source s to target t, and seeks the route that arrives at τ first. The Earliest Arrival Problem is formally defined as follows (Pajor 2009).

Definition 6: The Earliest Arrival Problem

Given a time independent or time dependent network, source and target points s and t in the network, as well as a departure time $\tau < \prod$, one is asked for a route in the network with the following properties:

i. *The route should start at vertex s: the source vertex.*
ii. *The departure time at s is τ.*
iii. *The route ends at vertex t: the target (i.e. sink) vertex.*
iv. *The length (i.e. travel time) of all other routes satisfying the properties i–iii should be bigger or at least equal.*

Note that property ii can be omitted, if the underlying network is time independent.

The term 'route' in this definition depends on the network type. For example, in the Private Vehicle Network (PVN), a route is simply a sequence of road segments; whereas in the Public Transport

Network (PTN), a route is an itinerary that informs the traveller which train/bus/IRPT to use and where to transfer. An itinerary is formally defined as follows (Pajor 2009).

Definition 7: Public Transport Itinerary

An itinerary is a sequence I of elementary connections from the respective timetables, in order that, for consecutive elementary connections c_i, $c_{i+1} \in I$, it holds that the arrival stop/station of c_i matches the departure stop/station of c_{i+1}. This yields a chain of elementary connections that can be used to travel through the network.

In a multimodal network, the road routes and the public transport itineraries are combined in order to obtain a supernetwork.

THE SHORTEST PATH PROBLEM

The Shortest Path Problem (SPP) can be defined as follows (Pajor 2009).

Definition 8: The Shortest Path Problem

Given a weighted, directed time independent, -time dependent or -mixed graph $G = (V, E)$, a source vertex $s \in V$, a target vertex $t \in V$ and a departure time $\tau < \prod$, one is asked for a shortest path $P^* = [v_1, \ldots, v_k]$ with the following properties:

1. *i. The path begins at vertex s, thus $v_1 = s$.*
2. *ii. The path ends at vertex t, thus $v_k = t$.*
3. *iii. For all paths P' having the properties i and ii, it has to hold that $len(P', \tau) \geq len(P, \tau)$.*

Note that, if G is time independent, τ is ignored and the length of a path P is obtained by len P.

According to Pajor (2009), there are three closely related problems which are all variations of the Shortest Path Problem. An explanation of each follows.

1. Many-to-many SPP.

This is a generalisation of the SPP. Instead of one vertex for both s and t, one is given a set of source vertices $S \subseteq V$ and a set of target vertices $T \subseteq V$, and is then asked for a shortest path P* for each pair $(s, t) \in S \times T$. *In multimodal routing, the Earliest Arrival Problem will essentially transform to this version of the problem.*

2. One-to-all SPP.

This is a special case of the many-to-many SPP where S is a singleton set consisting of one source vertex s and T = V is the set of all vertices. One is then asked for the shortest paths to every vertex $v \in V$. Furthermore, because the edge set of all resulting paths $T = {}_{v \in V} P_v$ forms a tree, one might also say that a shortest path tree is computed.

3. All-pairs SPP.

This is a version of the many-to-many SPP where both S and T are the complete vertex set V of the graph. If the all-pairs SPP is solved automatically, solutions for all instances of the SPP in the graph are included. However, (pre)computing shortest paths for all pairs of vertices tend to be very extensive: both regarding memory consumption and the execution time required. Therefore, this is evidently not a viable approach for large graph sizes.

Each of these variations of the SPP can be solved with Dijkstra's algorithm.

THE EARLIEST ARRIVAL- AND THE SHORTEST PATH PROBLEM IN THE PTN

Pajor (2009) states that, in the time dependent Public Transport Network (PTN), with or without realistic transfer times, a (time dependent) shortest path results in the following itinerary: each time a connection edge is used in the network, the interpolation point that was used for evaluating the edge, yields a connection from the timetable that was used on the respective edge. And since, in each version of the model, the only way to get from one stop/station to another stop/station is by using a connection edge, the sequence of obtained connections from the timetable thus forms a valid itinerary. Therefore, if the path in the graph is a shortest path with some departure time τ from the source stop/station, this itinerary is a solution to the Earliest Arrival Problem with departure time τ.

DIJKSTRA'S ALGORITHM

Dijkstra (1959) considered the following design problem: assume a graph with n vertices that has some or all pairs of the vertices connected by an edge, and with the length of each edge given. Also assume that at least one path (i.e. an edge) exists between any two vertices. With this problem statement, Dijkstra (1959) developed an algorithm that determines a path of minimum total length (i.e. weight) between any two given vertices in the graph. This algorithm is known world-wide as Dijkstra's Shortest Path Problem.

This classic algorithm for shortest paths starts with a source vertex s as root and grows a tree that contains shortest paths from s to all other vertices. A vertex that already belongs to the tree is said to be settled (i.e. discarded). If a vertex u is settled, a shortest path $P*$ from s to u has been found. A vertex that is adjacent to a settled vertex is said to be reached. (Note that a settled vertex is also reached.) Vertices that are not reached are classified as unreached (Geisberger *et al.* 2010). The algorithm continues to find shortest paths from the reached vertices until all the vertices have been settled.

Dijkstra's algorithm can also be augmented to solve time dependent and time independent routing. However, because Dijkstra's algorithm requires linear computation time[16], Goldberg (2001) states that it is too slow for practical applications in today's real world transport networks. Furthermore, Dijkstra's algorithm, when applied to multimodal graphs, may result in undesirable routes. Consider the following hypothetical example given in Pajor (2009).

> Assume that one is given a multimodal graph that consists of a Private Vehicle Network (PVN) and a Public Transport Network (PTN). Now consider a traveller who wishes to traverse with the railway network. He/she will probably go to the nearest railway station, either by car or by foot, and then take a train to the destination station, from where he/she will probably conduct the last part of the journey either by foot or taxi in order to reach the wanted destination point. If there is however, for example, a freeway (somewhere in the middle of the railway network applicable to the traveller's journey) which runs parallel to the railway tracks, Dijkstra's algorithm might, when considering travel time, regard it as beneficial to get off the train, use the freeway (by car) and then to re-board another train at the end of the freeway. In general, this can happen relatively often.

The problem is that, with multimodal routing, the traveller has a rather strict opinion regarding to what a 'good' path should look like. Regardless of this, even though such a path might be the fastest, it is not applicable, since the traveller probably does not have a car available to him/her in the middle of his/her journey.

Refer to Figure 26 (Pajor 2009): the black edges depict car edges, the red edges railway edges and the blue edges foot edges.

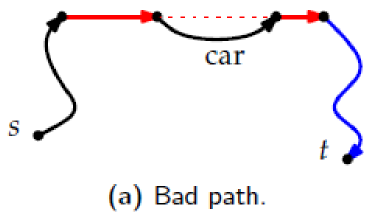


FIGURE 26: A DEPICTION OF A GOOD- AND A BAD ROUTE

One way to incorporate constraints (that restrict the set of feasible paths in multimodal routing) is to augment the classic SPP to the Label Constrained Shortest Path Problem in which finite state automata and language theory are encompassed.

[16] If the input size is large enough, the running time of the algorithm increases linearly with the size of the input.

4.6.2. MULTIMODAL ROUTING ALGORITHMS

THE LABEL CONSTRAINED SHORTEST PATH PROBLEM

An elegant approach that restricts and coordinates modal transfers, referred to as the Label Constrained Shortest Path Problem (LCSPP), was first proposed by Mendelzon and Wood (1989). In the LCSPP, the edges are labelled, and the sequence of the edge labels has to comply with elements of a language (passed as query input) for any feasible path (Dibbelt *et al.* 2012). The LCSPP can be formally defined as follows (Pajor 2009).

Definition 9: The LCSPP

*Given an alphabet Σ, a language $L \subset \Sigma^*$, a weighted, directed graph **G = (V, E, c, ℓ)** with Σ-labelled edges and source- and target vertices s, t ∈Σ; one is asked for a shortest path P* from s to t, where the sequence of labels along the edges of the path forms a word of L. Thus given $P^* = [v_1, \ldots, v_k]$, it has to hold that: $label(v_1, v_2), label(v_2, v_3) \ldots label(v_{k-1}, v_k) \in L$.*

The problem formulation of the LCSPP demands no restriction on the language L. Barrett *et al.* (2000) however expanded the LCSPP to use a generalisation of Dijkstra's algorithm. With this adapted approach the language used in the LCSPP has to be regular, hence the name: Dijkstra's Regular Language Constrained – DRegLC – shortest path problem. Barrett *et al.* (2000) further found that, if the language L used to denote the edge labels is regular, the space- and time bounds of the LCSPP are improved.

DIJKSTRA'S REGULAR LANGUAGE CONSTRAINED SHORTEST PATH PROBLEM

The general idea of DRegLC shortest path problem is to find a shortest path from a source vertex s to a target vertex t, with starting time τ_{start}, on a labelled and directed graph **G**, by minimizing some cost function (time or distance), with the concatenated labels along the shortest path satisfying a word of a given regular language L. Thus, the regular language is used to model the traveller's constraints on the sequence of the labels (e.g. exclusion of labels (i.e. mode preference), predefined order of labels, etc.) (Kirchler *et al.* 2012).

APPLICATION: MULTIMODAL JOURNEYS

Consider the following hypothetical example given in Barrett *et al.* (2008).

> Assume a traveller wants to take a bus from a start point s to a target point t and suppose that transfers are undesirable, while walks from s to a bus stop and from a bus stop to t are allowed.

To solve such a problem, the graph needs to encompass a vertex for every bus stop and an edge between each consecutive pair of stops. Then by using a regular language, the edges need to be labelled according to the modes of travel allowed. For this particular situation, assume f for walking (foot network) and b for bus transit. The traveller's restriction can now be modelled as f∗b∗f*. If the traveller's transit however also requires transfers between the bus stops, an additional constraint needs to be modelled. That is, that the network contains a zero length f-edge for each change of bus.

The formal definition of DRegLC shortest path problem, as stated in Barrett *et al.* (2008), is as follows.

Definition 10: DRegLC Shortest Path Problem

Given a finite alphabet Σ; a weighted, directed graph $\mathbf{G = (V, E, c, \ell)}$ *with cost function* $c: E \rightarrow \mathbb{R}+$ *and label function* $\ell: E \rightarrow \Sigma$; *a regular language* $L \subseteq \Sigma^*$; *and a query* $(s, t) \in V \times V$; *find a shortest s-t-path* $P^* = (e_1, e_2, \ldots, e_k)$ *in* $\mathbf{G}$ *such that* $\ell(p) \in L$, *where* $\ell(p)$ *is the concatenation* $\ell(e_1) \cdot \ell(e_2) \cdots \ell(e_k)$ *of the labels of P*'s edges, and the weight (time or distance) of P* is the sum of the weights of P*'s edges.*

Kirchler *et al.* (2012) state that, DRegLC shortest path problem can be seen as the application of Dijkstra's algorithm to the product network. That is, the product of the multimodal network **G** and the finite automaton *A* describing the language constraints imposed by the traveller. Note that, by Kleene's theorem, a regular language can be represented through a Nondeterministic Finite Automaton (NFA), which inherently, allows for a concise description and can also be solved in polynomial time[17]. This concept of the product network is justified by the following theorem given in Barrett *et al.* (2008).

Theorem 2: Using the Product Network to find the Shortest Path

Finding a label constrained shortest path for some regular language $L \subseteq \Sigma^*$ *and a query* $(s, t) \in V \times V$, *is equivalent to finding a shortest path in the product network* $P = \mathbf{G} \times A$ *from the vertex* (s, q_0) *to* (t, f) *for some* $f \in F$.

[17] The running time of the algorithm is a simple polynomial function of the size of the input.

THE PRODUCT NETWORK

The product network is defined as follows (Barrett *et al.* 2008).

Definition 11: The Product Network

Consider the direct product of a weighted, Σ-labelled graph $\mathbf{G} = (V, E, c, \ell_G)$ *and a NFA* $A = (Q, \Sigma, \delta, q_0, F)$ *with set Q of states (i.e. vertices), alphabet Σ, transition function δ, start vertex* q_0*, and set F of final vertices. And let T be the set of state transitions* $t = (q_1, q_2)$ *with* $\delta(q_1) = q_2$ *and labels* $\ell_A(t) \in \Sigma$*. Then the product network (*$P = \mathbf{G} \times A$*) is defined to have:*

- *vertex set* $\{(v, q) \mid v \in V, q \in Q\}$ *and,*
- *edge set* $\{(e, t) \mid e \in E, t \in T, \ell_G(e) = \ell_A(t)\}$*, with the cost of an edge (e, t)* $\in P$ *corresponding to c(e).*

In Barrett *et al.* (2000), the following example is given. Assume $A_1 = (Q_1, \Sigma, \delta_1, p_0, F_1)$ and $A_2 = (Q_2, \Sigma, \delta_2, q_0, F_2)$ are two NFAs. The product NFA is then defined as $A_1 \times A_2 = (Q_1 \times Q_2, \Sigma, \delta, (p_0, q_0), F_1 \times F_2)$, where $\forall_a \in \Sigma$, $(p_2, q_2) \in \delta((p_1, q_1), a)$ if and only if $p_2 \in \delta_1(p_1, a)$ and $q_2 \in \delta_2(q_1, a)$. And $L(A_1 \times A_2) = L(A_1) \cap L(A_2)$.

THE METHOD

The method for implementing DRegLC shortest path problem, in the product network, as stated in Barrett *et al.* (2000), follows.

INPUT:

- A regular expression R.
- A weighted, directed graph **G**.
- A source s- and a destination t vertex.

CALCULATIONS:

- Construct an NFA $A(R) = (Q, \Sigma, \delta, q_0, F)$ from R.
- Construct the NFA $A(\mathbf{G})$ of **G**.
- Construct $P = A(\mathbf{G}) \times A(R)$. Choose the length of the edges in P to be equal to the corresponding edges in **G**.
- Starting from state (s, q_0), find the (many-to-many) shortest paths to the vertices (t, f) for some $f \in F$. Denote these paths by p_i, $1 \leq i \leq w$. Also denote the cost (i.e. weight) of p_i by $w(p_i)$.
- $C* = min_{pi}\, w(p_i)$; $p*: w(p*) = C*$. (If p∗ is not uniquely determined, an arbitrary one should be chosen.)

OUTPUT:

- The path p∗ in P from s to t, of minimum length, subject to the constraint that $\ell(p) \in L(R)$.

IMPLEMENTATION

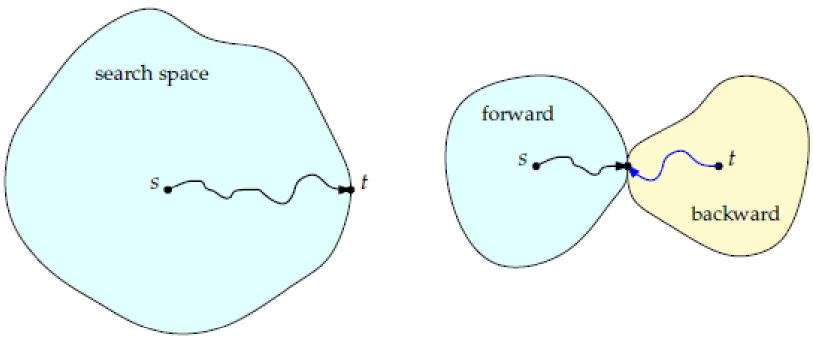
In Pajor (2009), DRegLC shortest path problem (based on the implementation method discussed above) has been implemented. Pajor (2009) found that a direct implementation of this algorithm can be computed in polynomial time. However, regarding the memory complexity, the space required to store the product graph P is in $\Theta(|\mathbf{G}|\cdot|A|)$ space. This complexity might make the modelling of large multimodal networks difficult. Fortunately, according to Pajor (2009), DRegLC shortest path problem can be augmented in such a way that the product graph P does not have to be computed explicitly in advance. Instead, if one uses **G** and the transition graph of *A*, separately, as input, the input space complexity is reduced to $\Theta(|\mathbf{G}|+|A|)$. With this proposition, the product network is computed implicitly only for the vertices and edges that are reached by Dijkstra's algorithm. And even though, in the worst case, Dijkstra's algorithm still visits the entire graph, thus, not improving on the theoretical complexity bound, these cases are deemed to be rare.

4.7. SPEED-UP TECHNIQUES

In order to compensate for today's large scale transport networks, research in the past few years have focussed on developing speed-up techniques to accommodate for routing problems evident in today's life. These speed-up techniques all have the same goal; that is, reducing the search space of routing algorithms such as Dijkstra's SPP, while still yielding demonstrable optimal results. The three techniques that will briefly be considered herein are: the bi-directional search, the goal-directed search and pre-processing contraction hierarchies.

4.7.1. BI-DIRECTIONAL SEARCH

If one computes a shortest s-t-path using uni-directional Dijkstra, the search starts at s and subsequently settles (i.e. discards) the vertices v until t is reached. Note that, once a vertex v is settled, it is never settled again. Thus, dist(v) is the shortest distance from s to v. Furthermore, for all vertices u, that were settled before v, it holds that dist(u) ≤ dist(v). However, the idea behind bi-directional routing is that, besides executing an s-t-query in G, a query from t to s, in the backward graph G, is also executed (Pajor 2009). The former is called the forward search and the latter the backward search. According to Barrett *et al.* (2007), while the forward search roughly explores k^2 vertices to find a k-edge shortest path, the forward- and backward searches are likely to meet when each has explored approximately $(k/2)^2$ vertices. Therefore, with the bi-directional search technique it is applicable to anticipate an expected halving of the number of explored vertices (compared to uni-directional Dijkstra). Refer to Figure 27 (Pajor 2009).



(a) Uni-directional Dijkstra. (b) Bi-directional Dijkstra.

FIGURE 27: THE SEARCH SPACE OF UNI- AND BI-DIRECTIONAL DIJKSTRA

4.7.2. GOAL-DIRECTED SEARCH (A*)

For given source- and target vertex, the goal-directed search (or A∗ search) adjusts the edge lengths so that edges pointing roughly towards the target vertex are preferred to those pointing away from it. According to Barrett *et al.* (2007), this could have the effect that potentially fewer vertices (and edges) need to be visited before the target is found. Furthermore, to ensure that optimal shortest paths are found, the Euclidean distance between any two vertices needs to be a valid lower bound on the actual shortest distance between these vertices. Barrett *et al.* (2007) state that this is typically the case for road networks, since the edge distance between two vertices in a road network often accounts for curves, bridges, etc., and is therefore equal to at least the Euclidean distance between the two vertices.

According to Geisberger *et al.* (2010), the most successful goal-directed approaches are ALT and Arc Flags. However, for the purpose of this research project, these techniques will not be considered.

4.7.3. PRE-PROCESSING CONTRACTION HIERARCHIES

Geisberger *et al.* (2010) state that, the combination of hierarchy and goal-direction is currently the most successful approach used in speeding-up processing time.

Pre-processing Contraction Hierarchies (CH) heuristically order the vertices of the graph by using an importance value. With aid of this importance value, all the vertices are contracted in order of ascending importance. According to Dibbelt *et al.* (2012), in order to contract a vertex $v \in V$, it needs to be removed from G, with shortcuts between its neighbours added to preserve the distances between the remaining vertices. The index at which v has been removed, is denoted by rank(v). To determine if a shortcut (u,w) needs to be added, a local search from u is executed (without looking at v), until w is settled: if $len(u,w) \leq len(u,v) + len(v,w)$, the shortcut (u,w) should not be added.

The CH query is thus a bi-directional Dijkstra search operating on G, augmented by the shortcuts computed during pre-processing. Both searches (i.e. forward and backward) go 'upward' in the hierarchy: the forward search only visits edges (u, v) where rank(u) ≤ rank(v), and the backward search only visits edges where rank(u) ≥ rank(v) (Dibbelt *et al.* 2012).

4.8. ITS APPLICATIONS NECESSARY FOR ACHIEVING A MULTIMODAL TRANSPORT SYSTEM

4.8.1. ADVANCED TRAFFIC MANAGEMENT SYSTEMS

Advanced Traffic Management Systems (ATMS) include ITS applications that focus on traffic control devices, such as adaptive traffic signal control, ramp metering, Variable Message Signs (VMS) and Traffic Operations Centres (TOCs). TOCs rely on information technologies in order to connect sensors and roadside equipment, vehicle probes, cameras, message signs, and other devices together to create an integrated view of traffic flow and to detect accidents, dangerous weather events, or other roadway hazards (Ezell 2010). These transport network operations are typically managed by a Transport Management Centre (TMC) and encompass Freeway Management Systems (FMS), Arterial Management Systems (AMS) and Urban Traffic Control (UTC).

FREEWAY MANAGEMENT SYSTEMS

According to Neudorff *et al.* (2006) the quality of day to day freeway operations, are classified by the following considerations: congestion, safety, mobility, accessibility and reliability/predictability.

Traffic congestion means there are more people trying to use a given transport facility during a specific period of time (i.e. demand) than the facility can handle (i.e. capacity), with what are considered to be acceptable levels of delay. *Safety* is concerned with reducing the number of vehicle crashes and minimising any injuries (as well as the probability of a fatality occurring) associated with crashes. *Mobility* is related to the ability and knowledge to travel from one location to another by using a multimodal approach. *Accessibility* is the means and ease by which an individual can accomplish some economic- and/or social activity. And *reliability/predictability* refers to how much the ease of movement varies from day to day, and the extent to which the traveller can predict these temporal variations (Neudorff *et al.* 2006).

The goal of Freeway Management Systems (FMS) is to manage these quality considerations. Examples of ITS applications used in FMS are: communication systems such as Variable Message Signs (VMS), a Highway Advisory Radio (HAR), ramp metering and Incident Management Systems (IMS). Ezell (2010) defines ramp metering as follows: traffic signals on freeway entrance ramps that break up clusters of vehicles entering the freeway, which reduces the disruptions to freeway flow that vehicle clusters cause and thus makes merging safer. According to Neudorff *et al.* (2006), IMS use surveillance- and detection systems to quickly detect, respond, and clear disabled vehicles and other events (such as debris) from the roadway that would detract from facility performance.

With these ITS applications in place, situations with a potential to cause congestion, unsafe conditions, reduced mobility, etc., can be promptly detected, and appropriate strategies and plans for mitigating these problems, and their duration and impacts on travel, can be implemented in a timely manner (Neudorff *et al.* 2006). As a result, FMS create informed drivers. And if a driver knows the extent and duration of, for instance, congestion, it not only gives him/her better options (i.e. advising drivers to take alternative routes), but it also removes a significant level of stress by making the unknown known to him/her.

ARTERIAL MANAGEMENT SYSTEMS

Arterial roadways are moderate capacity roadways (just below freeways in Level of Service: LOS[18]) that carry large volumes of traffic between areas in urban centres. A key distinction is that arterial roadways tend to use traffic signals.

Arterial Management Systems (AMS) can thus utilise similar technologies as FMS, but with the addition of adaptive traffic signal control. Adaptive traffic signal control refers to dynamically managed, intelligent traffic signal timing. This is achieved by giving traffic signals the ability to detect the presence of waiting vehicles and/or by giving vehicles the ability to communicate that information to a traffic signal. This is commonly done through DSRC-enabled communication. DSRC (Dedicated Short Range Communications) is a short- to medium range wireless communication channel, operating in the 5.8 or 5.9 GHz wireless spectrum, specifically designed for automotive uses (Ezell 2010).

If adaptive traffic signal control is used adequately, it could enable improved timing of traffic signals, thereby enhancing traffic flow and thus reducing congestion.

URBAN TRAFFIC CONTROL

Urban Traffic Control (UTC) utilises traffic detectors and probe vehicles (in conjunction with devices such as embedded GPS-receivers) to manage urban roadways.

Traffic detection is accomplished with a number of sensors. According to Papacostas and Prevedouros (2005), the most common sensor used, is inductive loop detectors. An inductive loop detector employs a wire sensor loop embedded in the roadway pavement to detect vehicles. A vehicle within the detection zone of the sensor affects the magnetic field of the loop by causing a

[18] LOS is a measure used by traffic engineers to determine the effectiveness of transport infrastructure.

decrease in its inductance. The two most basic functions, for which vehicle detectors are used, are presence- and passage detection. Presence sensors detect slow moving or stopped vehicles whereas passage sensors detect moving vehicles. Traffic detection thus facilitates the attainment of data that are representative of current traffic volumes and patterns in order to optimise traffic flow.

Probe vehicles (in conjunction with devices such as embedded GPS-receivers) are often deployed in taxis or government-owned vehicles (equipped with DSRC or other wireless technology) that report, on a frequent basis, their speed and location to a central Traffic Operations Centre (TOC). The TOC aggregates the probe data to generate an area-wide picture of traffic flow and to identify congested locations. Embedded GPS-receivers are mostly deployed in vehicles' on-board units. However, extensive research has also been performed into using mobile phones (that drivers often carry) as a mechanism to generate real time traffic information, using the GPS-derived location of the phone as it moves along with the vehicle (Ezell 2010). As mentioned previously, both Google's traffic option and TomTom HD traffic application utilise probe vehicles and devices such as embedded GPS-receivers.

4.8.2. ADVANCED PUBLIC TRANSPORT SYSTEMS

The evolvement of information technology (such as integrated systems, network- and wireless connectivity, expert systems and enterprise information systems) has created immense scope for growth in the utilisation of information systems within the public transport industry (Yahya and Noor 2008).

Advanced Public Transport Systems (APTS) include applications such as Automatic Vehicle Location (AVL), Electronic Fare Payment (EFP) with aid of Automated Fare Collection (AFC) and Interoperable Fare Management (IFM), and the provision of real time traffic information to public transport users via Advanced Traveller Information Systems (ATIS). AVL enables transit vehicles, whether bus or rail, to report their current location which again enables traffic operations managers to construct a real time view of the status of all assets in the public transport system (Ezell 2010). AVL thus facilitates ATIS and helps to provide public transport users with real time information, such as route guidance/navigation systems, real time transit status information, parking information and roadside weather information. For the purpose of this research project, EFP and ATIS will be considered.

ELECTRONIC FARE PAYMENT

Multimodal (and multi-operator) Automated Fare Collection (AFC) can be implemented using an electronic payment system in conjunction with some type of interoperable fare media as the payment mechanism.

In the context of fare collection, a distinction between fare- and fare media integration needs to be made. According to Mezghani (2008), fare integration is the possibility offered to passengers to travel from origin to destination by applying the same fare, whatever the mode or the operator used is, and with full transfer rights between modes and operators. (Helsinki's public transport pricing is an example of an integrated fare system.) Fare media integration is the possibility to use the same fare media (with possible limitation in time) to travel from origin to destination, whatever the mode or operator used is, and with full transfer rights between modes and operators. (Bilbao's Creditrans has an integrated ticket system. And Brussels' STIB offers integrated pricing and ticketing.)

An emerging popular fare media choice in public transport is the usage of smart card technology. According to Mezghani (2008), a smart card can be distinguished by two measures. That is, by the type of chip that it contains and by the type of interface it uses to communicate with the card reader. There are three different types of chips that can be associated with these cards: memory only, wired logic and microcontroller. And there are two primary types of chip card interfaces: contact and contactless.

Furthermore, when using smart card technology, an electronic purse (also denoted as e-purse) is used to implicate the monetary value stored on the card (Yahya and Noor 2008). According to Mezghani (2008), journey-based fare rate structures can be split into the following four categories:

1. Flat fare: all passengers are charged identical fares regardless of route, distance travelled, or type of passenger (e.g. age).
2. Route fare: each route has its own fare.
3. Zonal fare: the network is divided into zones, with a flat fare in each zone, and the price is determined according to the number of zones crossed by the passenger. (Paris' public transport system works on zonal fares.)
4. Distance-based fare: a price per km is applied in order to determine fare.

MYCITI'S MYCONNECT CARD

MyCiti's smart card system uses a banking card, known as an EMV (Europay, MasterCard and Visa) card, which contains a microcontroller chip and operates with a contactless chip card interface. Mezghani (2008) defines a microcontroller chip and a contactless chip card interface as follows:

- Microcontroller cards contain a microcontroller, an operating system, and read/write memory that can be updated many times. The secure microcontroller chip card contains and executes logic and calculations and stores data in accordance with its operating system.

- A contactless chip card only needs to be in near proximity to the reader (generally within 10 cm) for data exchange to take place. The data exchange takes place over Radio Frequency (RF) waves and the device that facilitates communication between the card and the reader are RF antennae internal to both the card and the reader.

The journey-based fare rate structure that MyCiti wishes to accomplish is the distance-based fare rate. Within the near future, a MyCiti traveller will be prompted to tap his/her MyConnect card at the Point of Sale (POS) device upon boarding and again upon disembarking a MyCiTi bus. The distance travelled will then be calculated and the MyCiti traveller will pay the according fare with the second tap upon disembarkment. However, MyCiti is pursuing an integrated fare media system. Refer to Figure 28.

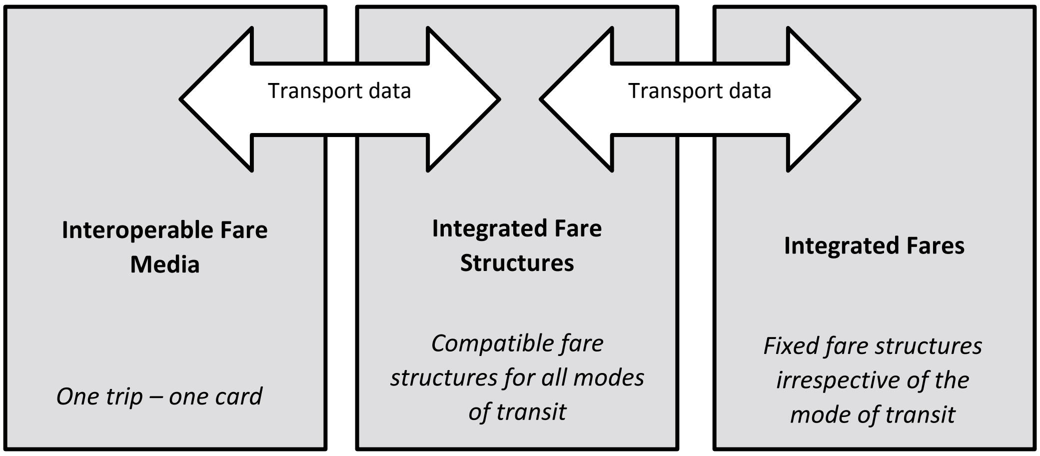


FIGURE 28: THE MULTIMODAL AFC STRUCTURE

As can be seen in Figure 28, MyCiti's goal with the usage of their MyConnect card is to ultimately allow travellers to transit seamlessly between different modes of transport, regardless of their mode choice, by only using one payment mechanism. A Cape Town minibus-taxi association has already launched their card (the Tap-i-Fare card), which is showing the interoperability of the system with Tap-i-Fare customers using their cards on MyCiTi buses. Therefore, as banks and transport entities become more involved, this distance-based fare rate will be met within an integrated fare media system.

This author believes that the smart card service will make public transport more appealing to and more convenient for the travellers, since the probability of fraud occurring is reduced and the need to carry exact cash for payment is removed. Moreover, when a traveller uses his/her smart card on a transport operator's vehicle that is enabled with a POS device, information is automatically triggered through a transaction transmitted to a data hub repository. In this data hub repository, the read and process of a variety of information regarding cash inputs, travel- and network usage, is possible. And if data mining[19] principles are applied to this electronic ticketing data, one can obtain a operators' performance statistics (e.g. bus ridership by counting all bus boardings, service frequencies/headways by analysing the time interval between buses/trains, and bus/train arrival time at stops/stations by determining the first person who taps his/her smart card at a stop/station, etc.) as well as valuable information on card usage and travel patterns. All of this information can then be utilised for policy, planning and marketing usages (Mezghani 2008).

ADVANCED TRAVELLER INFORMATION SYSTEMS

Advanced Traveller Information Systems (ATIS) provide travellers with real time travel- and traffic information, such as transit routes and schedules; navigation directions; and information about delays due to congestion, accidents, weather conditions, or road repair work (Ezell 2010). By implementing ATIS, dynamic route guidance, real time traffic conditions, and en route information may be provided, in an integrated manner, to the travellers (Zhang, L. *et al.* 2011).

Hansen *et al.* (1994) categorised the ATIS information service media into four groups:

1. Automated telephone information systems.
2. Computer data retrieval systems.
3. Interactive audio/video systems.
4. Display announcement systems.

According to Hansen *et al.* (1994), most automated telephone information- and computer data retrieval systems are mainly designed for pre-trip planning; whereas interactive audio/video- and display announcement systems are primarily designed to inform travellers who are away from their home or workplace, whether en route or at a transport terminal.

Hansen *et al.* (1994) state that the proper implementation and promotion of automated telephone information- and computer data retrieval systems could enhance, supplant, or replace the manual telephone systems currently employed by many transit operators. By either eliminating the need for a human operator (at least for some types of information requests) or increasing the speed and accuracy with which the operator can respond to information requests, these technologies thus have the potential to reduce costs and increase the convenience and availability of the many present-day manual systems. Furthermore, Hansen *et al.* (1994) state that interactive audio/video- and display announcement systems have the ability to facilitate inter- and intramodal connections, allow travellers to plan activities that conform to the transit schedule, offer sports- and

[19] Data mining is the process of analysing existing information in order to extract patterns from the data; used mainly to find previously unknown correlations between variables, to detect trends and to make behavioural predictions that may be commercially useful.

entertainment options, and may be of particular value in assisting way finding for travellers with either vision or hearing impairments.

For the purpose of this research project, the development of a computer data retrieval system will be considered. More specifically, since journey planning constitutes a common decision faced by many travellers, the development of an ATIS, portraying pre-trip, on-trip and end-trip information, will be researched.

4.9. THE DEVELOPMENT OF A CENTRALISED DATABASE

4.9.1. DATABASE VERSUS DATA WAREHOUSE

Hammergren and Simon (2009) define data warehousing as the coordinated, architected, and periodic copying of data from various (internal and external) sources, into an environment optimised for analytical and informational processing. Therefore, by using a data warehouse (DW), the barriers created by non-enterprise, process-focused applications are broken down, and information is consolidated into a single view for users to access.

The differences between a database (DB), as was defined previously, and a DW, are depicted in Table 4 (Bontempo and Zagelow 1998).

TABLE 4: DATA WAREHOUSE VERSUS DATABASE

Data Warehouse	Database
Subject oriented	Application oriented
Integrated	Limited integration
Non-volatile	Continuously updated
Stabilised data values	Current data values only
Ad hoc retrieval	Predictable retrieval

For the application required in this research project, where the importance of providing transport users with real time data is stressed, the design of a DB and not a DW will thus be considered.

THE IDEA BEHIND A CENTRALISED DATABASE

The basic idea behind the development of a centralised database can be seen in Figure 29. The aim is to consolidate all the transport information in a centralised database. This has the advantage that Advanced Traveller Information Systems (ATIS) only need to access a central repository to retrieve all the relevant information quickly. Therefore, facilitating fast information retrieval to the transport users, whether for unimodal- or multimodal traversals.

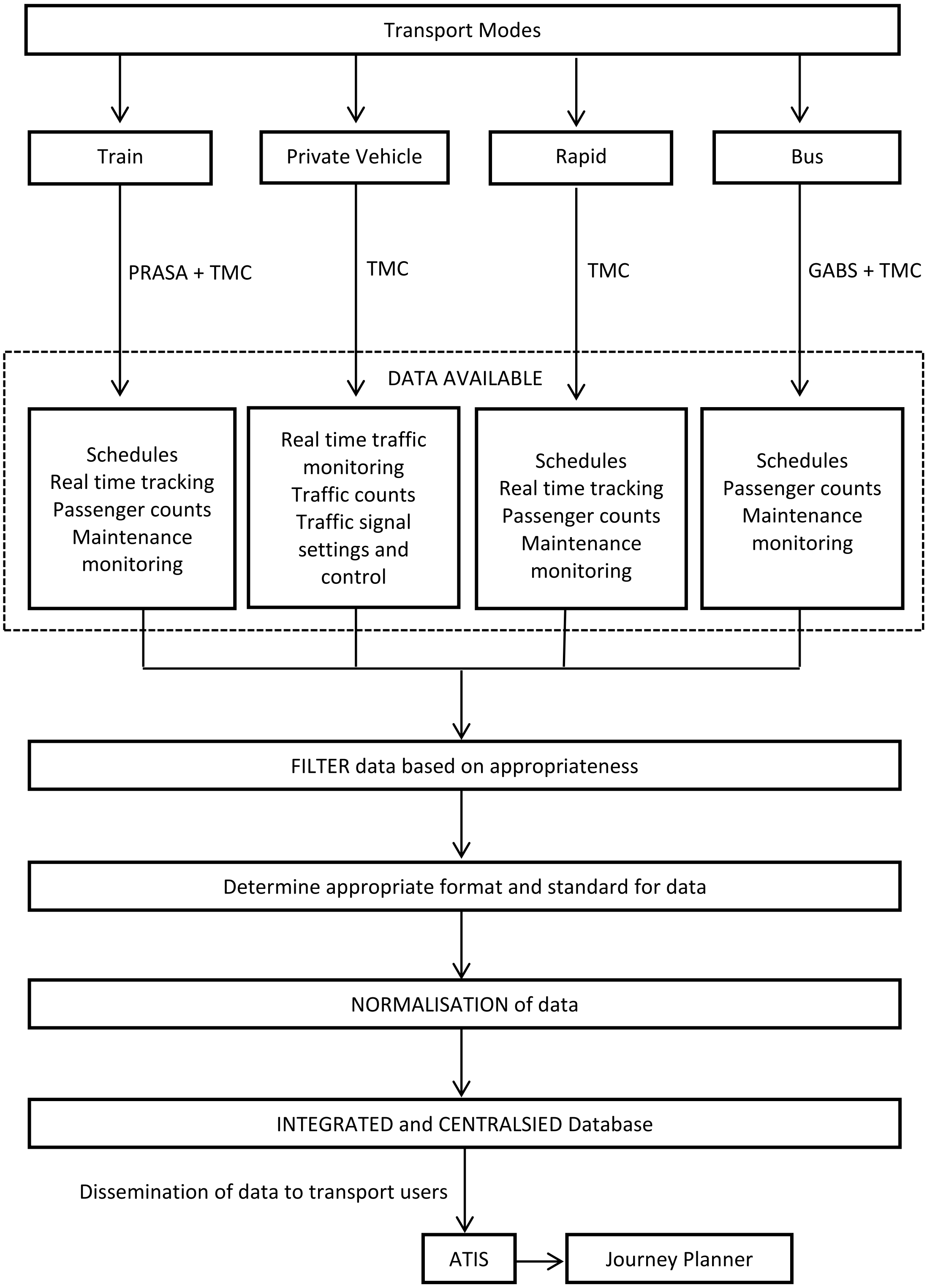


FIGURE 29: THE IDEA BEHIND A CENTRALISED DATABASE

4.9.2. MANAGING A DATABASE

In order to manage a DB effectively, a Database Management System (DBMS) needs to be in place. Refer to Figure 30 (Taylor 2003).

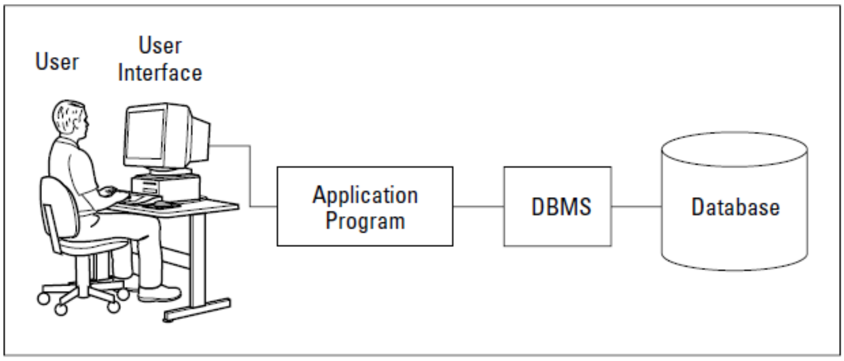


FIGURE 30: AN INFORMATION-BASED DBMS EXAMPLE

Elmasri and Navathe (2011) define a DBMS as the collection of programs that enables users to create and maintain a DB. It is a general-purpose software system that facilitates the processes of defining, constructing, manipulating, and sharing databases among various users and applications.

- **Defining a DB** involves specifying the data types, the data structures, and the constraints of the data that is to be stored in the DB. This descriptive information (i.e. the DB definition) is stored by the DBMS in a database dictionary in the form of meta-data[20].
- **Constructing the DB** is the process of storing the data on some storage medium that is controlled by the DBMS.
- **Manipulating a DB** includes functions such as querying[21] the database to retrieve specific data, updating the database to reflect real time/world changes, and generating reports from the data. (As seen in Figure 30, an application program accesses the DB by sending queries or requests for data to the DBMS. A query typically causes some data to be retrieved and a transaction may cause some data to be read and some data to be written into the DB.)
- **Sharing a DB** allows multiple users and programs to access the database simultaneously.

Other important functions provided by the DBMS, as stated in Elmasri and Navathe (2011), include protecting and maintaining the database. DB protection includes system protection against hardware- or software malfunction, and security protection against unauthorised access. Furthermore, since a typical DB may have a life span of many years, the DBMS is also responsible

[20] Data about data.

[21] The term query, originally meaning a question or an inquiry, is loosely used for all types of interactions with databases; i.e. retrieving and modifying the data.

for maintaining the database system by allowing the system to evolve as the requirements change over time.

THE CLASSIFICATION OF A DBMS

The type of DBMS required can, in an overall manner, be classified according to the application type and the desired modelling needs.

OnLine Transaction Processing (OLTP)

OLTP refers to a class of systems that facilitate and manage transaction-oriented applications, typically for data entry and retrieval transaction processing (Wikipedia 2012).

Operational Data Store (ODS)

An ODS is a database designed to integrate data from multiple sources for additional operations on the data. The data is then passed back to operational systems for further operations and to the data warehouse for reporting (Wikipedia 2012).

OnLine Analytical Processing (OLAP)

In computing, OLAP is an approach to swiftly answer Multi-Dimensional Analytical (MDA) queries. OLAP is part of the broader category of business intelligence, which also encompasses relational reporting and data mining.

Data Mart/Data Warehouse (DM/DW)

A DM is the access layer of the data warehouse environment that is used to get data out to the users. The data mart is a subset of the DW that is usually oriented to a specific business line or team. A DW is a central repository of data which is created by integrating data from multiple unrelated sources (Wikipedia 2012).

Refer to Table 5 (Scalzo 2010) to view the functionality of each application type with respect to one another. For the purpose of this research project, OLTP will be utilised since it facilitates the functionality of real time data being processed and retrieved on the fly.

TABLE 5: THE NATURE OF THE APPLICATION

	OLTP ✔	ODS	OLAP	DM/DW
Business Focus	Operational	Operational Tactical	Tactical	Tactical Strategic
End User Tools	Client Server Web	Client Server Web	Client Server	Client Server Web
DB Technology	Relational	Relational	Cubic	Relational
Transaction Count	Large	Medium	Small	Small
Transaction Size	Small	Medium	Medium	Large
Transaction Time	Short	Medium	Long	Long
Size in Gigs	10 – 200	50 – 400	50 – 400	400 - 4000
Normalisation[22]	3NF	3NF	N/A	0NF
Data Modelling	Traditional ER	Traditional ER	N/A	Dimensional

4.10. MODELLING DATA WITH A RELATIONAL DATABASE

4.10.1. IMPORTANT CONCEPTS

CATEGORIES OF DATA MODELS

Data models are characterised according to the type of concepts they use to describe the database (DB) structure. According to Elmasri and Navathe (2011), two extremes exist: high-level (or conceptual)- and low-level (or physical) data model. The former provides concepts that are close to the way many users perceive data. The latter provides concepts that are typically meant for computer specialists. That is, concepts that describe how the data is stored on the computer storage media, typically magnetic disks. Between these two extremes, a class of representational data models exists. Representational data models, as stated in Elmasri and Navathe (2011),

[22] Normalisation is a systematic way of ensuring that a database structure is suitable for general-purpose querying and free of certain undesirable characteristics (that could lead to loss of integrity) by minimising redundancy and dependency.

provide concepts that may be easily understood by the end users, but that are not too far removed from the way data is organised in computer storage. These models include the widely used relational data model as well as the legacy data model (i.e. the network- and hierarchical model). Legacy data models have been widely used in the past, but the relational data model is used in most of today's commercial databases.

SCHEMAS, INSTANCES AND DATABASE STATE

In any data model, it is important to distinguish between the description of the database and the database itself.

The description of a database is called the **database schema**. And each object in the database schema is called a **schema construct**. According to Elmasri and Navathe (2011), most data models have the convention of displaying schemas as diagrams. As a result, a displayed schema is called a **schema diagram**. It should be noted that a schema diagram however only displays some aspects of a database schema, such as the names of record types and the data items.

The database schema is specified during database design and is not expected to change frequently. However, the actual data in a database may change somewhat over time. Therefore, Elmasri and Navathe (2011) define the data in the database at a particular moment in time as the **database state**. Many database states can be constructed to correspond to a particular database schema.

The distinction between database schema and database state is very important. When a new database is defined, its database schema is specified only to the DBMS. At this stage, the corresponding database state is the empty state with no data. The initial state of the database is obtained when the database is (for the first time) populated with the initial data. From then on, every time an update operation is executed, another database state is obtained. And at any point in time, the database has a current state (Elmasri and Navathe 2011).

4.10.2. DEFINING THE RELATIONAL DATABASE

A database organised in terms of the relational data model is referred to as a relational database.

THE RELATIONAL DATA MODEL

The relational data model is a logical data model that defines how data should be represented in the DBMS. Moreover, Dobre *et al.* (2010) state that this model is used in most of today's commercial databases due to it being well-known for its simplicity. That is, the data is represented through values that are structured with only one construct: the ‘relation’.

According to Elmasri and Navathe (2011), when a relation is thought of as a table of values, each row in the table represents a collection of related data values, with all the values in a column having the same data type. The row in the table represents a fact that typically relates to a real world entity or relationship. And the table- and column names are used to interpret the meaning of the values in each row of the table. In the formal relational data model terminology, as stated in Elmasri and Navathe (2011), a row is called a tuple, a column header is called an attribute, and the table is called a relation. And the data type describing the types of values allowed in each column is represented by a domain of possible values.

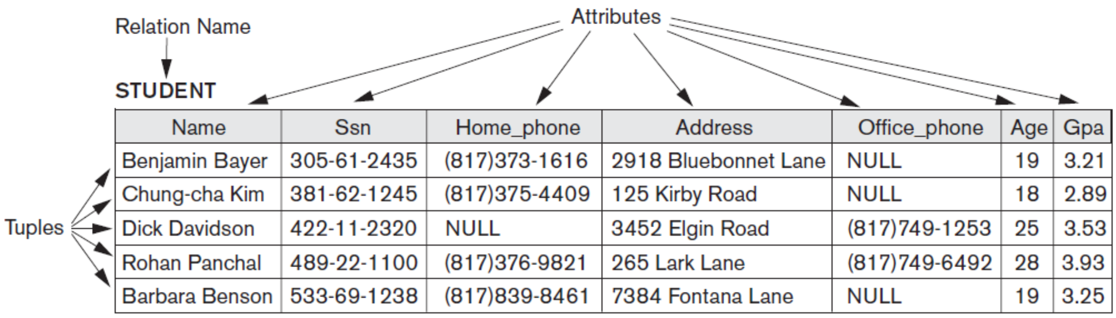
DOMAINS, ATTRIBUTES, TUPLES, RELATIONS AND RELATION SCHEMAS

Elmasri and Navathe (2011) define a domain **D** as a set of atomic values. That is, each value in the domain is indivisible as far as the formal relational model is concerned. A common method of specifying a domain is to give the domain a name, and to specify a data type (e.g. string, integer, character, etc.) and -format (i.e. the structure of the data) from which the data values forming the domain, are drawn.

A <u>relation schema</u> **R**, denoted by R(A_1, A_2, … , A_n), is made up of a relation name R and a list of attributes: A_1, A_2, … , A_n. The degree of a relation is equal to the number of attributes (i.e. n) in the relation schema. Each attribute $\mathbf{A_i}$ is the name of a role played by some domain D in the relation schema R. D is thus referred to as the domain of A_i and is denoted by dom(A_i) (Elmasri and Navathe 2011).

A relation **r** of the relation schema R(A_1, A_2, … , A_n), also denoted by r(R), is a set of n-tuples r = {t_1, t_2, … , t_m}. Each n-tuple is an ordered list of n values defined as **t** =<v_1, v_2, … , v_n>, where each value $\mathbf{v_i}$ (for $1 \leq i \leq n$) is an element of dom(Ai) or is a special NULL value[23] (Elmasri and Navathe 2011).

In the example in Figure 31 (Elmasri and Navathe 2011), the relation is displayed as a table, where each tuple is shown as a row and each attribute corresponds to a column header indicating a role or interpretation of the values in that column.



Name	Ssn	Home_phone	Address	Office_phone	Age	Gpa
Benjamin Bayer	305-61-2435	(817)373-1616	2918 Bluebonnet Lane	NULL	19	3.21
Chung-cha Kim	381-62-1245	(817)375-4409	125 Kirby Road	NULL	18	2.89
Dick Davidson	422-11-2320	NULL	3452 Elgin Road	(817)749-1253	25	3.53
Rohan Panchal	489-22-1100	(817)376-9821	265 Lark Lane	(817)749-6492	28	3.93
Barbara Benson	533-69-1238	(817)839-8461	7384 Fontana Lane	NULL	19	3.25

FIGURE 31: AN EXAMPLE OF A RELATION I.E. STUDENT

[23] NULL values represent attributes whose values are unknown, undefined, do not exist or exist but is not available, for some individual tuple.

CONSTRAINTS

The schema-based constraints include (Elmasri and Navathe 2011):

- Domain constraints.
    - Constraints that specify that, within each tuple, the value of each attribute A should be an atomic value from the domain dom(A).
- Constraints on NULL values.
- Primary key constraints.

Due to the fact that the formal relational data model is defined as a set of tuples, and by definition, all elements of a set are distinct, all tuples in a relation should therefore also be distinct. This means that no two tuples can have the same combination of values for all their attributes. Therefore, a uniqueness constraint, that is, that no two distinct tuples in any state r of R can have the same value, is needed.

According to Elmasri and Navathe (2011), every relation has at least one unique default: i.e. the set of all its attributes. However, a relation can have redundant attributes. Consequently, the concept of a primary key - an identifier that has no redundancy - was developed.

A primary key is time-invariant (i.e. it continues to hold when new tuples are inserted into the relation) and it uniquely identifies the tuples in a relation. In certain circumstances, it is however possible that a relation can have more than one candidate key applicable for acting as the primary key. For example, Figure 32 (Elmasri and Navathe 2011) has two candidate keys: License_number and Engine_serial_number.

CAR

License_number	Engine_serial_number	Make	Model	Year
Texas ABC-739	A69352	Ford	Mustang	02
Florida TVP-347	B43696	Oldsmobile	Cutlass	05
New York MPO-22	X83554	Oldsmobile	Delta	01
California 432-TFY	C43742	Mercedes	190-D	99
California RSK-629	Y82935	Toyota	Camry	04
Texas RSK-629	U028365	Jaguar	XJS	04

FIGURE 32: THE CAR RELATION WITH 2 CANDIDATE KEYS

In such a situation, one of the candidate keys needs to be designated as the primary key of the relation. The choice of which candidate key is to become the primary key is somewhat arbitrary. However, it is usually better to allocate the roll of primary key to the candidate key with a single attribute or a small number of attributes (Elmasri and Navathe 2011).

THE RELATIONAL DATABASE SCHEMA

In a relational database, there will typically be many relations, and the tuples in those relations are usually related in various ways. Therefore, the state of the whole database will correspond to the states of all its relations at a particular point in time (Elmasri and Navathe 2011). This gives rise to the concept of a relational database schema.

RELATIONAL DATABASE SCHEMA AND -STATE

A relational database schema **S** is a set of relation schemas S = {R_1, R_2, ... , R_m} and a set of Integrity Constraints (IC). A relational database state (DB of S) is a set of relation states DB = {r_1, r_2, ... , r_m} such that each r_i is a state of R_i and such that the r_i relation states satisfy the IC specified (Elmasri and Navathe 2011).

In Figure 33 (Elmasri and Navathe 2011), a relational database schema: COMPANY = {EMPLOYEE, DEPARTMENT, DEPT_LOCATIONS, PROJECT, WORKS_ON, DEPENDENT}, is shown. The underlined attributes therein represent primary keys.

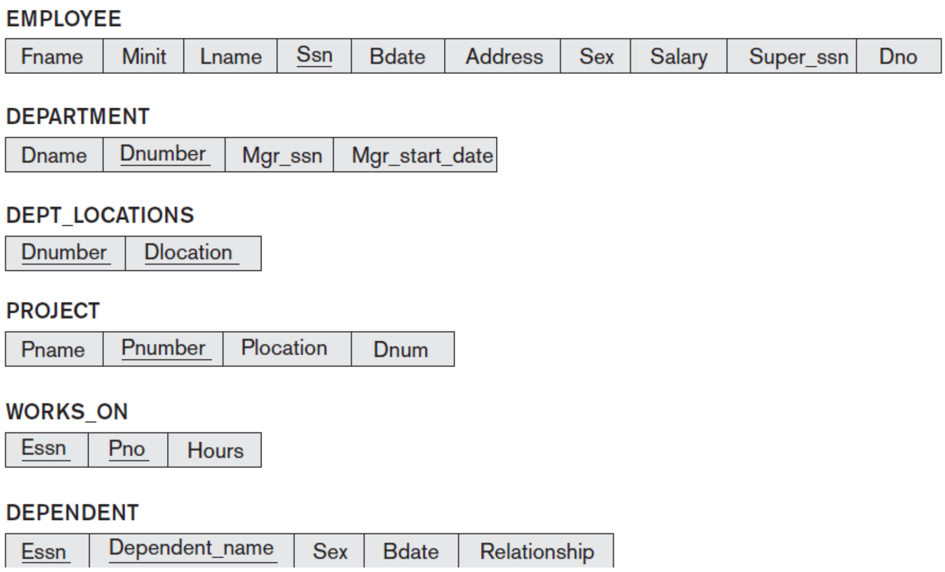


FIGURE 33: A SCHEMA DIAGRAM FOR THE COMPANY RELATIONAL DATABASE SCHEMA

In Figure 34 (Elmasri and Navathe 2011), a relational database state corresponding to the COMPANY schema, is shown.

EMPLOYEE

Fname	Minit	Lname	Ssn	Bdate	Address	Sex	Salary	Super_ssn	Dno
John	B	Smith	123456789	1965-01-09	731 Fondren, Houston, TX	M	30000	333445555	5
Franklin	T	Wong	333445555	1955-12-08	638 Voss, Houston, TX	M	40000	888665555	5
Alicia	J	Zelaya	999887777	1968-01-19	3321 Castle, Spring, TX	F	25000	987654321	4
Jennifer	S	Wallace	987654321	1941-06-20	291 Berry, Bellaire, TX	F	43000	888665555	4
Ramesh	K	Narayan	666884444	1962-09-15	975 Fire Oak, Humble, TX	M	38000	333445555	5
Joyce	A	English	453453453	1972-07-31	5631 Rice, Houston, TX	F	25000	333445555	5
Ahmad	V	Jabbar	987987987	1969-03-29	980 Dallas, Houston, TX	M	25000	987654321	4
James	E	Borg	888665555	1937-11-10	450 Stone, Houston, TX	M	55000	NULL	1

DEPARTMENT

Dname	Dnumber	Mgr_ssn	Mgr_start_date
Research	5	333445555	1988-05-22
Administration	4	987654321	1995-01-01
Headquarters	1	888665555	1981-06-19

DEPT_LOCATIONS

Dnumber	Dlocation
1	Houston
4	Stafford
5	Bellaire
5	Sugarland
5	Houston

WORKS_ON

Essn	Pno	Hours
123456789	1	32.5
123456789	2	7.5
666884444	3	40.0
453453453	1	20.0
453453453	2	20.0
333445555	2	10.0
333445555	3	10.0
333445555	10	10.0
333445555	20	10.0
999887777	30	30.0
999887777	10	10.0
987987987	10	35.0
987987987	30	5.0
987654321	30	20.0
987654321	20	15.0
888665555	20	NULL

PROJECT

Pname	Pnumber	Plocation	Dnum
ProductX	1	Bellaire	5
ProductY	2	Sugarland	5
ProductZ	3	Houston	5
Computerization	10	Stafford	4
Reorganization	20	Houston	1
Newbenefits	30	Stafford	4

DEPENDENT

Essn	Dependent_name	Sex	Bdate	Relationship
333445555	Alice	F	1986-04-05	Daughter
333445555	Theodore	M	1983-10-25	Son
333445555	Joy	F	1958-05-03	Spouse
987654321	Abner	M	1942-02-28	Spouse
123456789	Michael	M	1988-01-04	Son
123456789	Alice	F	1988-12-30	Daughter
123456789	Elizabeth	F	1967-05-05	Spouse

FIGURE 34: A POSSIBLE DB STATE FOR THE COMPANY RELATIONAL DATABASE SCHEMA

CONSTRAINTS

The constraints applicable to a relational database schema are (Elmasri and Navathe 2011):

- Domain constraints.
- Constraints on NULL values.
- Primary key constraints.
    - Constraints that ensure that there is no two distinct tuples in any state r of R can have the same value.
- Integrity Constraints (IC).
    - Entity integrity constraint states that no primary key value can be NULL.

- Referential integrity constraints maintain the consistency conditions related to foreign keys. That is, when a set of attributes in relation schema R_1 is a foreign key of R_1 that references relation schema R_2, the consistency among the tuples in the two relations is maintained by using referential integrity constraints. Refer to Figure 35 (Elmasri and Navathe 2011).

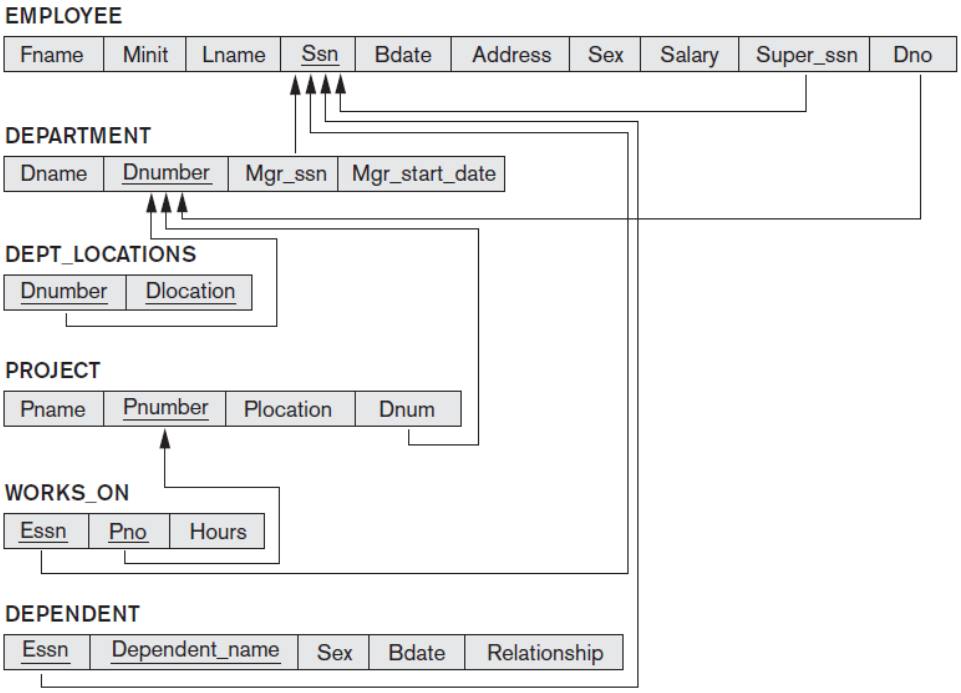


FIGURE 35: REFERENTIAL IC OF THE COMPANY RELATIONAL DB SCHEMA

4.11. MANAGING THE RELATIONAL DATABASE

According to Elmasri and Navathe (2011), most of the DBMSs are using Structured Query Language (SQL) to create, modify, maintain, and provide security for relational databases.

4.11.1. STRUCTURED QUERY LANGUAGE

SQL is a nonprocedural language. With procedural languages such as Pascal and Java, the database user tells the system how to get him/her what he/she wants by writing procedures. However, with SQL, the database user does not need to specify how the information is to be retrieved. On the contrary, the database engine (i.e. DBMS) examines the database and decides (for itself) how to fulfil the database user's request. Therefore, the database user needs only specify what data it is he/she wants to retrieve (Taylor 2003).

SQL COMPONENTS

The SQL command language consists of a limited number of commands that specifically relate to data handling. Some of these commands perform data definition functions; some perform data manipulation functions; and others perform data control functions. Taylor (2003) defines these SQL command languages as follows:

- Data Definition Language (DDL).

The DDL is the part of SQL that one uses to create and completely define the database, to modify its structure, and to destroy it when it is no longer needed.

- Data Manipulation Language (DML).

The DML performs database maintenance and is used to specify what one wants to do with the data in the database: enter it, change it, or extract it.

- Data Control Language (DCL).

The DCL protects the database from becoming corrupted. And if used correctly, it provides the necessary security authentication to the database. The amount of protection required however depends on the implementation: if the implementation does not provide sufficient protection, that protection needs to be added to the application program.

DATA DEFINITION LANGUAGE

The DDL is the part of SQL one uses to create, change, or destroy the basic elements in a relational database (Taylor 2003). These basic elements include tables, views, schemas, etc., and can be explained through the database containment hierarchy. That is, data is stored in the columns and rows of the tables, a collection of columns and rows form a view, and so on. Refer to Figure 36.

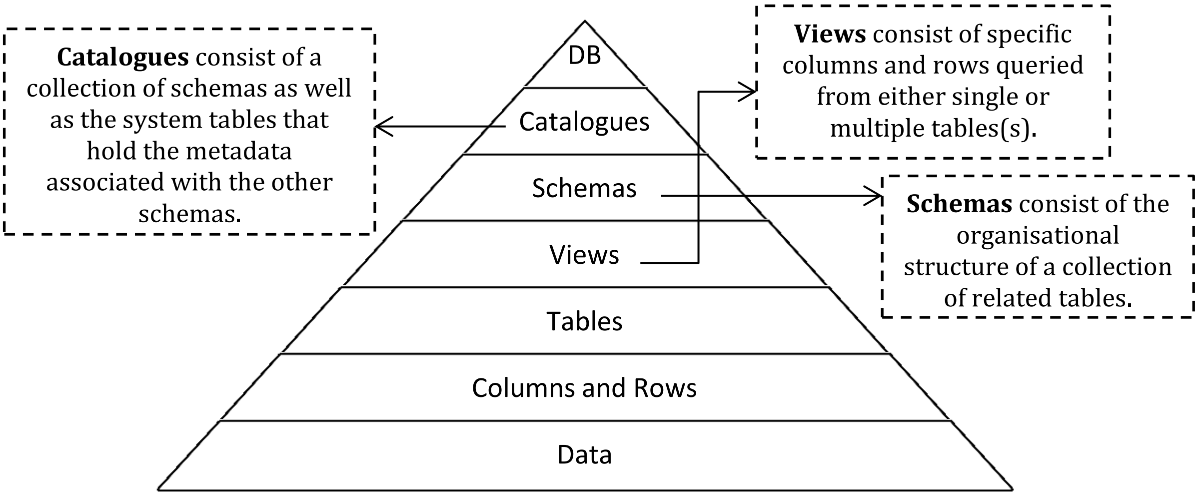


FIGURE 36: THE DATABASE CONTAINMENT HIERARCHY

The DDL consists of the following three commands (Taylor 2003):

- CREATE: This command is used to build the essential structures of the database.
- ALTER: This command is used to change the database structures created.

- DROP: This command can be used to destroy not only the table's data, but also its structure.

DATA MANIPULATION LANGUAGE

Whereas the DDL is the part of SQL that creates, modifies, or destroys database structures and hence does not deal directly with the data, the DML is the part of SQL that operates on the data.

The DML statements one can use are: INSERT, UPDATE, DELETE, and SELECT. These commands can be used to insert, update, delete or select (i.e. view) the values in a table. Moreover, these command statements can consist of a variety of parts, including multiple clauses. Each clause may encompass: value expressions (i.e. numeric, string, date/time, etc.), predicates (i.e. comparison operators: <, >, etc.), logical connectives (i.e. compound predicates with AND, OR and NOT), aggregate functions (i.e. COUNT, MAX, MIN, SUM and AVG), and sub-queries (Taylor 2003). Therefore, by using DML and thus including these clauses in one's statements, one can make fine judgments among database records and hence extract more (exact) information from the data.

DATA CONTROL LANGUAGE

The DCL are all used to protect the database from harm; either accidental or intentional. According to Taylor (2003), the DCL consist of four commands: COMMIT, ROLLBACK, GRANT, and REVOKE.

If for example a software or hardware failure occurs while a transaction is in progress, a database may be left in an indeterminate state between where it was before the change started and where it would be if it were able to finish. With the COMMIT statement, SQL can keep track of a transaction's progress. And if anything is to interrupt a transaction before the COMMIT statement ends the transaction, one can restore the system to its original state by issuing the ROLLBACK statement (Taylor 2003).

The Database Owner[24] (DBO) can grant access to the users by specifying their privileges (e.g. read, write or read and write) in the GRANT statements. And any privileges that are not explicitly granted are automatically withheld by SQL. After having been granted access, a user needs to pass an authentication procedure to prove his identity before he/she can access the files. Moreover, if the DBO uses the REVOKE statement, previously granted privileges can be withdrawn if and when needed (Taylor 2003).

[24] The DBO is the creator of, for example, a schema.

4.12. THE MULTIMODAL INFORMATION SYSTEM

4.12.1. THE USER INTERFACE

According to Kendall and Kendall (2008), the user interface has two main components: presentation language (which is the computer-to-human part of the transaction) and action language (which characterises the human-to-computer part of the transaction). Together, both these components cover the form and content of the term user interface.

Some examples of the different kinds of user interfaces, as given in Kendall and Kendall (2008), are:

- Natural-language interfaces.

  With this interface, the user interfaces with the computer using every day, or natural, language. An example is the website Ask.com: the user enters his/her search query and Ask.com responds with a list of responses that match the query entered by the user.

- Question-and-answer interfaces.

  With this interface, the computer displays a question to the user. To interact, the user enters an answer (via a keyboard stroke or a mouse click). The computer then reacts on the input information in a pre-programmed manner, typically by moving to the next question.

- Menus.

  With this interface, the user is provided with an onscreen list (i.e. menu) of available choices. In responding to the menu, the user is thus limited to the options displayed. For example, with a typical word processing menu, users can choose from the Edit, Copy or Print options.

- Graphical User Interfaces (GUI).

  With this interface, the user is provided with continuous and constant feedback on task accomplishment. Therefore, changes in operations can be made quickly, without incurring error messages. GUI can be used on extranets, intranets and on the Web.

4.12.2. THE CLIENT-SERVER ARCHITECTURE

According to Kendall and Kendall (2008), the information architecture model that will likely dominate networking in the next few years is that of the client-server. In such a model, the tasks or workloads are partitioned between the service requesters (i.e. the clients) and the providers of a resource or service (i.e. the servers).

The client-server architecture is based on an underlying framework that consists of many PCs and workstations as well as a smaller number of mainframe machines, connected via LANs (Local Area Networks) and other types of computer networks. A client in this framework is typically a user machine that provides user interface capabilities and local processing. When a client however requires access to additional functionality that does not exist at that machine, it connects to server that provides the needed functionality. The server is thus a system that contains both the hardware and software needed to meet the requests from the client machines (Elmasri and Navathe 2011).

THE N-TIER CLIENT-SERVER ARCHITECTURE

A tier is a functionally separated hardware- and/or software component. Therefore, a n-tier architecture is a client-server architecture in which applications, service components, and their distributed deployment, are logically separated among the n-tiers. According to California Technology Agency (2012), n-tier architectural platforms typically place each service, or group of services, on a separate server, enabling systems to be divided into easily scalable components.

THE 2-TIER CLIENT-SERVER ARCHITECTURE

In a 2-tier client-server architecture, the software modules of the Database Management System (DBMS) are divided between client- and server machines as follows (Elmasri and Navathe 2011):

- The server machine includes the part of the DBMS software responsible for handling data storage on disk pages, local concurrency control and recovery, buffering and caching of disk pages, and other such functions.
- The client machine handles the user interface; data dictionary functions; DBMS interactions with programming language compilers; global query optimisation, concurrency control, and recovery across multiple servers; structuring of complex objects from the data in the buffers; and other such functions.

THE 3-TIER CLIENT-SERVER ARCHITECTURE FOR WEB APPLICATIONS

In California Technology Agency (2012) it is stated that the 3-tier architecture is the most common used application of the n-tier architecture. In the 3-tier architecture, an intermediate layer between the client and the database server is added. Refer to Figure 37 (Elmasri and Navathe 2011).

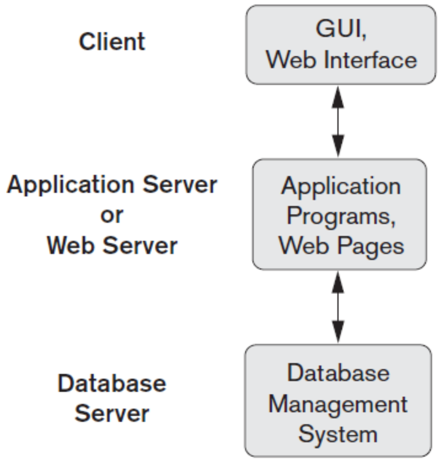


FIGURE 37: THE 3-TIER ARCHITECTURE

This intermediate layer (or middle tier) is called the application server or the web server, depending on the application required. According to Elmasri and Navathe (2011), this server plays an intermediary role by running application programs and storing business rules (e.g. procedures or constraints) that are used to access data from the database server. Moreover, it can also aid in improving database security by checking a client's credentials before forwarding a request to the database server.

The intermediate server accepts requests from the client, processes the request and sends database queries and commands to the database server, and then acts as a channel for passing (partially) processed data from the database server to the clients, where it may be processed further and filtered to be presented to users through a user interface such as the Graphic User Interface (GUI) format (Elmasri and Navathe 2011). The 3-tier architecture can therefore also be classified as: the user interface, the application rules, and the data access act.

SQL AND THE CLIENT-SERVER SYSTEM

SQL is a data sublanguage that can work on a stand-alone system or on a multi-user system. According to Taylor (2003), by using SQL in a client-server system, one can encode very complex operations into SQL at the client machine and then decode and perform those operations at the server machine. Moreover, Taylor (2003) states that this type of setup results in the most effective bandwidth use of the communication channel: if one retrieves data by using SQL on a client-server system, only the data one wants, travels across the communication channel from the server- to the client machine. Therefore, SQL works particularly well in a client-server system since the client-server architecture complements the characteristics of SQL to provide good performance, at a moderate cost, on small, medium, and large networks.

4.12.3. NETWORK ARCHITECTURE: TOPOLOGIES

The four main computer network architectures, according to their representing network topologies, are (Kendall and Kendall 2008):

1. Hierarchical (aka Tree) networks.

In a hierarchical configuration, the host (i.e. the mainframe computer) is positioned at the top most level and controls all the other nodes (e.g. PC's workstations, etc.) in an ordered, level by level, fashion with no communication between nodes on the same level. With this type of arrangement, large-scale computing problems are handled by the mainframe computer, and lesser computing demands are delegated to the correct levels to be handled by its representing nodes. Refer to Figure 38 (Uysal and Misirli 2009).

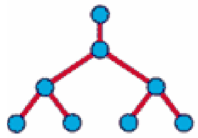


FIGURE 38: HIERARCHICAL TOPOLOGY

2. Star networks.

In the star configuration, a mainframe computer is designated as the central node. As such, it communicates with the lesser nodes, but they cannot communicate directly with one another. If the lesser nodes want to communicate with one another, a data request needs to be sent to the central node, which in turn would relay the data to the appropriate lesser node(s). Refer to Figure 39 (Uysal and Misirli 2009).

FIGURE 39: STAR TOPOLOGY

3. Ring networks.

In the ring configuration, there is no host or central computer. Rather, all the nodes have equal computing power and thus all nodes can communicate directly with one another, passing along all the messages they read to the correct destination on the ring. Refer to Figure 40 (Uysal and Misirli 2009).

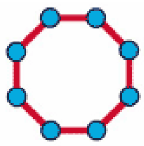


FIGURE 40: RING TOPOLOGY

4. Bus configuration.

In the bus configuration, each computer or server is connected to the single (bus) cable. A signal from the source travels in both directions to all the nodes connected on the (bus) cable until it finds the intended recipient. And if the computer address does not match the intended address for the data, the computer ignores the data. Or alternatively, if the data matches the computer address, the data is accepted. Refer to Figure 41 (Uysal and Misirli 2009).

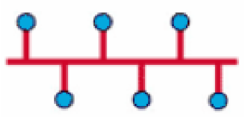


FIGURE 41: DATA BUS TOPOLOGY

4.13. THE DEVELOPMENT OF A MULTIMODAL JOURNEY PLANNER: ATIS

As mentioned previously, for a developing country like South Africa, the economic- and social health of the nation, depend to a large extent, on the performance of its public land transport system. However, Kasturia and Verma (2010) state that the success of the public transport system depends, to a larger extent, on the development of an efficient Advanced Traveller Information System (ATIS). Public transport travellers are usually not well aware of or informed about of the spatial- and temporal variations in transit services. Chorus *et al.* (2010) state that numerous studies have uncovered the travellers' dislike of knowledge limitations and their inclination to reduce these knowledge limitations by acquiring information. With a good ATIS in place, this need for information may be met. If the travellers are provided with comprehensive- and accurate information about their travel options, their travel behaviour (with respect to mode choice, time- and cost of travel, route choice, or trip making) may be influenced towards viewing public transport, within a multimodal platform, as their preferable means of transport.

4.13.1. THE VALUE OF INFORMATION

The definition of value of information, used in Herrala (2007), is based on three general theories: information theory, value theory and utility theory. A synopsis of each, as given in Herrala (2007), follows:

1. The information theory concentrates on creating, storing and communicating as much data as possible.
2. According to the value theory, the basic functions of value are definition, meaning, dimensions, roles and evaluation.
3. The utility theory links value and value theory to customer demands and benefits they can get by using the product.

Refer to Figure 42 (Herrala 2007).

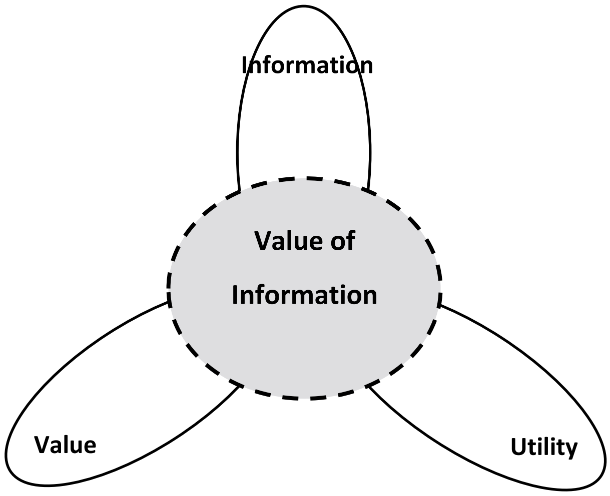


FIGURE 42: THE VALUE OF INFORMATION

According to Herrala (2007), in order to evaluate the value of information, the following three considerations need to be assessed:

1. The information quality attributes. The following quality measures need to be considered:
    a. Accessibility: the ease of use and ease of access of information. It includes the media through which the information is delivered as well as the reliability of the information system.
    b. Contents: information can be divided into information about the physical environment and information about the behaviour of the individuals. This information content should be organised in a way that it is of use to users.
    c. Availability: refers to how often information is available when it should be. It can be seen as a collection of the coverage, volume and consistency of the information system.
    d. Timeliness: refers to how up to date information is. The time at which the data is sent and received is often critical for decision-making. It may affect the expected payoff and cause the loss of opportunity. Out-of-date information is usually of little or no value.
    e. Validity: in social sciences, validity means the extent to which a measuring instrument measures what it is intended to measure. In logic and as an information quality attribute, it rather means that with true premises one cannot end up in false conclusion.
    f. Effectiveness: the effect information has on the user. Effective information may change the user's behaviour or his/her way of perceiving the surroundings.

   g. Cost: relates to the attributes of acquiring or providing the information. Only information, which cost is less than its perceived value, should be produced or acquired.

2. The information valuator. The following viewpoints need to be considered:
   a. The user: the centre of the information system.
   b. The firm: the provider (the one with the idea of offering information services to users and customers), the customer (transport companies who provide the services to their employees, aka the end users), and the supplier (the one who delivers the information to the customers).
   c. The society.
3. The information service value chain. To get a better grasp of the idea of different information valuators, refer to Figure 43 (Herrala 2007). In this figure, the value chain of information services, from the collection of raw data to delivering the information to the users, are shown.

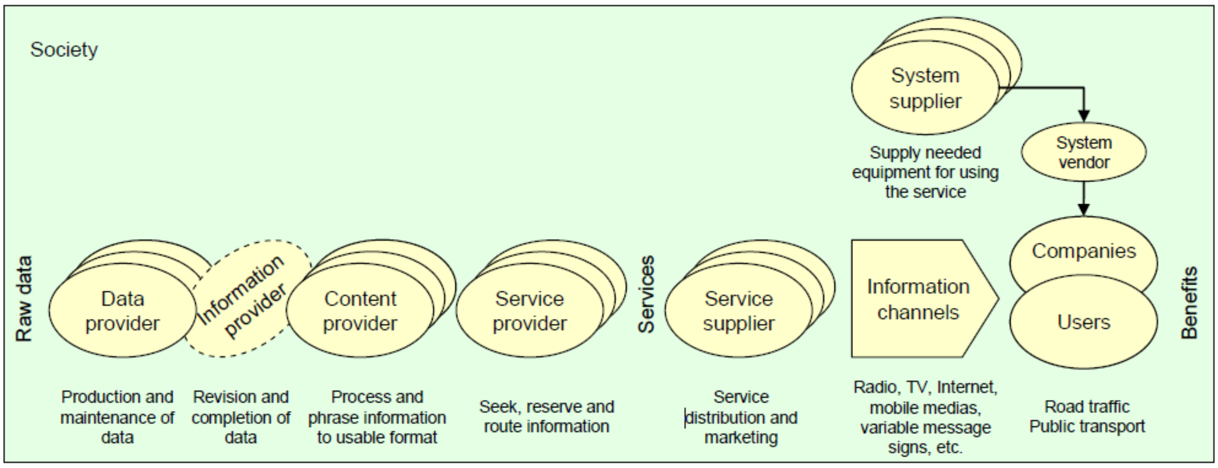


FIGURE 43: THE VALUE CHAIN OF INFORMATION SERVICES

With the aid of Figure 43 (Herrala 2007), the value of information can more easily be evaluated from the user's, the firm's and the society's point of view; and one can also get a holistic view of the value of information at the different stages therein. In Herrala (2007) it is stated that, the value of information varies and changes further along the value chain. Usually, as the information moves along the value chain, its value increases, because of the processing and phrasing of the data. However, sometimes, the information quality can also decrease. That is, because the information goes through and is handled by so many different parties, it may happen that, after all the modifications and the time spent in processing the data, the information has become irrelevant or out-dated when finally reaching the end users.

4.12.2 TRAVELLER INFORMATION NEEDS ACCORDING TO THE PHASE IN TRANSIT

As mentioned previously, a traveller's information needs are influenced by the phase he/she is in. That is, whether he/she is in the pre-trip, the on-trip or the end-trip phase. The travellers' information needs relating to the entire lifecycle of his/her journey are represented in Table 6 (Zografos *et al.* 2010).

TABLE 6: INFORMATION NEEDS ACCORDING TO TRIP PHASE

TRIP PHASE	INFORMATION NEEDS
Pre-trip	• Storing and accessing personal trip information anytime and anywhere. • Additional itinerary information customised to the international traveller profile with special emphasis on transfer navigation. • Online journey booking capabilities. • Information on and timely notification for managing any disruption of the selected itinerary before the commencement of the journey.
On-trip	• On-trip information for managing any unexpected disruption of a journey. • Provision of on-trip real time information to increase situation awareness of the traveller for his/her journey. • On-trip information on the schedule of the journey. • On-trip information to navigate the traveller during various phases of his/her journey.
End-trip	• Additional tourist information. • Additional information for private car drivers. • Additional information for taxi services. • Additional information on the orientation of the last part of the journey; i.e. from the public transport stop/station to the destination point.

In Chorus *et al.* (2010), a number of new empirical findings are reported. According to Chorus *et al.* (2010), it appears that travellers on non–business trips attach particular importance to mean travel times, while ignoring travel time variability; whereas during business trips, travel time variability also plays an important role. Furthermore, it was found that travellers generally have intrinsic preferences for some types of information over others, preferences that do not necessarily coincide with the economic value of information. More specifically, it was found that having unknown alternatives generated, is preferred over assessing known alternatives (Chorus *et al.* 2010).

4.13.3 THE INFORMATION SERVICES TRAVELLERS DEEM AS IMPORTANT: A CASE STUDY

In Zografos *et al.* (2010), a study of 25 internet-based Journey Planners (JPs) in Europe, China and Japan (as listed previously), was performed. The objective of this study was to identify and propose the travellers' information requirements that should be met in designing an integrated multimodal journey planning system.

In this study, the limitations of the existing systems were identified through the assessment of the information services offered under the following criteria: 1) transport modes covered, 2) sufficiency of static journey information provided, 3) geographical coverage, 4) quality of information display, 5) sufficiency of itineraries offered, 6) real time information capability, 7) sufficiency of on-trip information provision, 8) ticket booking capability, and 9) the means for information service accessibility (Zografos *et al.* 2010). In this research project, the assessment results of only criteria 1, 5, 6 and 9 will be discussed.

AN ASSESSMENT OF THE INFORMATION SERVICES PROVIDED

Firstly, half of the responses received in Zografos *et al*. (2010) related to **single mode** JPs. And although there were examples of rail- and private car single mode JPs, most single mode JPs provided information on bus services. Furthermore, Zografos *et al*. (2010) concluded that there appears to be two groups of **multimodal** JPs: those offering public transport solutions by using a variety of possible modes; and those that offer private car journey information in addition to public transport options in order to enable car owners to make informed decisions about whether to drive or not.

Secondly, almost all JPs reviewed in Zografos *et al*. (2010) calculated **itineraries** based on minimising en-route time as well as providing the option of minimising the number of transfers. The Finnish, German, Danish and Japanese JPs also allowed for minimising walking time.

Thirdly, **real time information** provision was claimed for many of the JPs studied in Zografos *et al*. (2010). However, this often related to travel news updates on traffic conditions and delays for presentation on the JP website <u>and not</u> to real time data used in the JP route optimisation or to alert users of real time delays and thus then advising them on alternative journey options. Notable exceptions to this, as determined in Zografos *et al*. (2010), are: the Greek City JPs where real time forecasts of urban bus arrivals and departures are provided; the Dutch 9292ov JP where real time congestion and delays for public transport are provided; and Yahoo Route Selection in Japan that uses online real time information according to the actual operational status of all modes of transport covered by the JP (i.e. bus, rail and air).

And lastly, Zografos *et al*. (2010) determined that the journey planners reviewed from the United Kingdom, Finland, Germany, Denmark, Greece and the Netherlands largely enable **communication and information exchange** via SMS, whereas those from Italy, Spain, China and Japan do not. Interesting enough, Zografos *et al*. (2010) also concluded that telephone call centres still form an important part of the JP package. This human interface is still viewed as essential for large sections of the population; those who are not PC literate or those who have no access to internet and mobile technologies.

THE CONCLUSIONS DRAWN FROM THE RESULTS OBTAINED

Zografos *et al*. (2010) identified the main limitations for many of the JPs reviewed to be related to difficulties experienced in the supply of data. Some of the problems mentioned by the respondents were: differing data formats provided by different suppliers of data; gaps in service data provided to the data manager; unwillingness of some transport operators to provide data; difficulties of updating and maintaining large quantities of data from many different sources; the frequency with which changes in service data occur; and a lack of real time update of information.

The analysis of the findings from the JPs studied has led to the identification of the following five main limitations (Zografos *et al.* 2010):

1. Lack of personalised travel information and information customised on the traveller's profile.
2. Availability of fare information and ticket booking capabilities are very limited since they are only provided for specific transport services.
3. Limited on-trip information (e.g. real time alerts) to travellers.
4. Limited use of dynamic- and real time data in journey planning services.
5. Limited alternative travel options. The existing JPs determine alternative itineraries on the basis of a single criterion (i.e. en-route time, walking time, number of transfers, or cost). As a result, it is left to the traveller to compare alternative itineraries under two or more criteria.

In addition, a major outcome concluded form the analysis presented in Zografos *et al*. (2010), was that there seems to be a consensus among the travellers (from the different countries involved in the study) concerning the most important information services. According to Zografos *et al*. (2010), the following types of traveller information services were rated with the highest weight of relative importance:

- Traveller-centred (i.e. customised) door-to-door journey planning.
- Personalised real time alerts and travel reminders.
- Dissemination of travel information through the Internet and mobile phones.

4.13.4 THE TRAVELLERS' CHOICE BEHAVIOUR ON INFORMATION SERVICE MEDIA: A CASE STUDY

Zhang, X. *et al.* (2009) conducted a study to determine the factors that influence the travellers' choice behaviour of service media. The investigation of public transit information requirements was carried out in the city of Dalan, Iran, in May 2007. In this study, just over 500 questionnaires were analysed and statistical inference was conducted by using a binary logistic regression model.

The questionnaires included four transit information service media: Internet, mobile phone, TV, and transit facilities. The factors that influence the public travellers' choice behaviour of the information service media were categorised into three main groups. Refer to Table 7 (Zhang, X. *et al.* 2009).

TABLE 7: VARIABLES OF MEDIA CHOICE MODELS

FACTOR GROUPS	FACTORS
Personal attributes	Gender (Male or female) Age (Under 20 years old, 21-30 years old, 31-40 years old, 41-50 years old, 51-60 years old and over 60 years old) Vocation (Worker, official, student, tourist and retired people)
Information attributes	Public transit information • Urban-oriented maps • Public transit network • Bus timetables • Traffic information • Scenic spots • Sports and entertainment
Usage of internet and mobile phone	Always Seldom Never

The results obtained in Zhang, X. *et al.* (2009), indicated that the variables of vocation, the type of information and the usage of internet and mobile phone, have a significant influence on the choice of media; whereas the variables of age and gender only have an influence on some of the choice of media.

Moreover, Zhang, X. *et al.* (2009) found that the travellers' demand for urban-oriented information maps enhances the probability of travellers' choice of internet. Similarly, because mobile phones can assist travellers with the provision of real time information (e.g. the bus timetables and traffic information), the demand for this type of information enhances the probability of the travellers' choice of mobile phones. Zhang, X. *et al.* (2009) also concluded that the vocation variables have the most significant influence on the choice of service media. The vocation variables' influence on the choice of internet, mobile phone and transit facilities have statistical significance. However, these variables have no significance on the choice of TV. That is, because TV is a mass media, Zhang, X. *et* *al.* (2009) found that most travellers' choice of TV (regardless of their vocation) does not have dramatic differences.

4.13.5 THE PROVISION OF PERSONALISED INFORMATION

As mentioned previously, Automated Fare Collection (AFC) systems can be used to mine, and thus reveal, individual differences in travel patterns. Furthermore, if AFC is used in conjunction with RFID technology, transport users can be provided with personalised information about their chosen route(s) (e.g. the provision of personalised trip time estimates and relevant notifications). However, this personalisation is dependent on the deployment of an electronic ticketing system, and ultimately, the attainment of an Interoperable Fare Management (IFM) structure.

A MODEL FOR IFM

An IFM structure is based on an AFC system in which a (contactless) smart card can be used on several modes of transport, operated by several independent transport operators, and used in several locations.

As can be seen in Figure 44 (this figure was altered from a similar IFM structure found in Mezghani (2008)) an IFM structure is obtained by achieving level three.

The dilemma is that, if a transport operator is not sure about which level he/she is confronted with or which level he/she needs a solution for, he/she might end up with a completely over-qualified or under-qualified AFC system. This can result in very high costs at the beginning of an electronic ticketing project, or very high expenses at a later stage of a project when updates and modifications are required. Mezghani (2008) thus recommends that transport operators use available standards and open specifications (including for example: security, data model, and transmission) as much as possible in order to avoid costly implementations of proprietary and non-compatible systems.

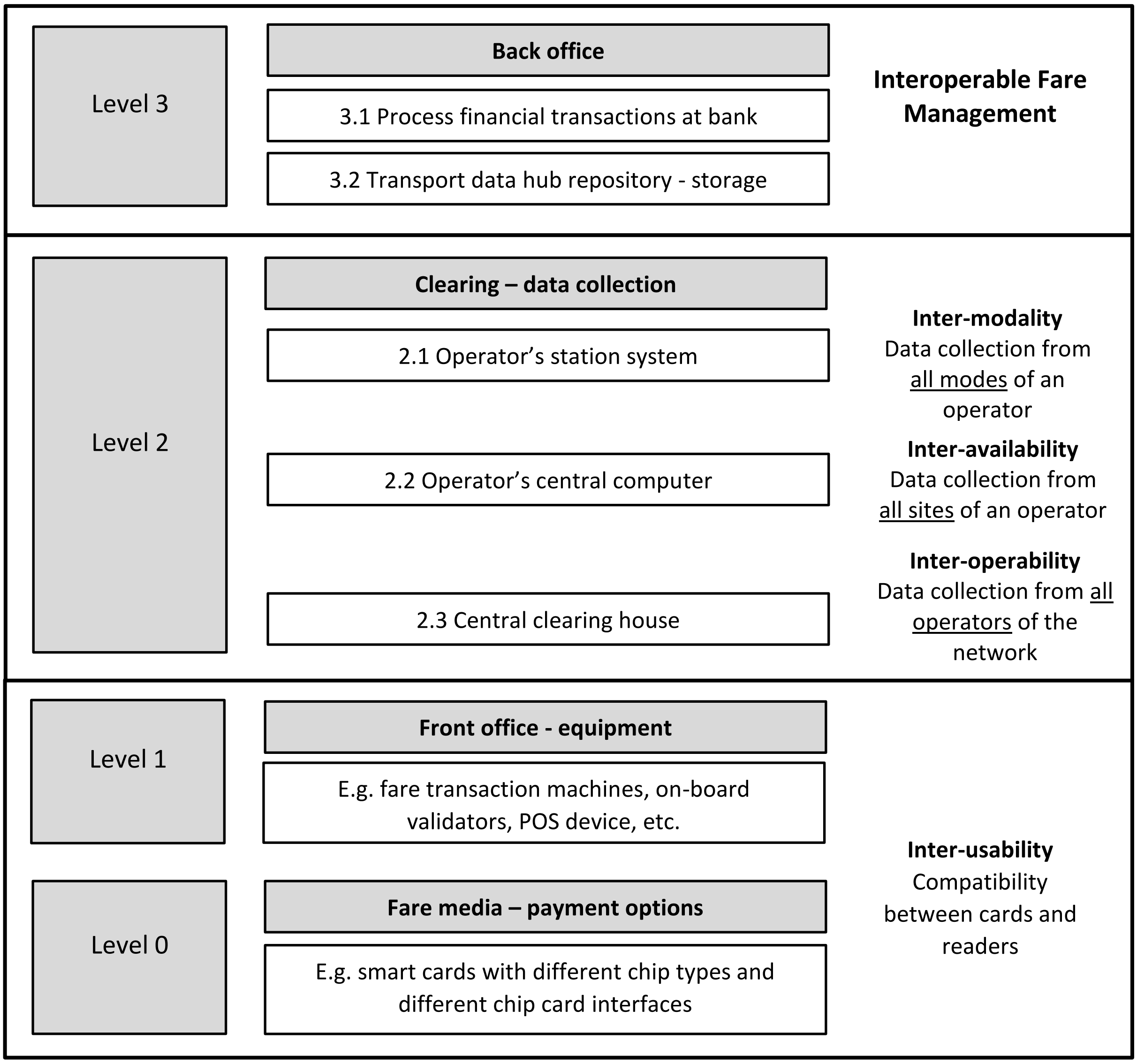


FIGURE 44: A POSSIBLE IFM STRUCTURE

A description of the levels depicted in Figure 44 follows:

Level 0

Level 0 is merely the input to level 1. That is, the fare media used.

Level 1

At level 1, the (contactless) smart card is only used on one means of transport, operated by one transport operator, and in one location. At this level, it is important that the fare media (supplied by the various suppliers) is accepted by all front-end equipment (also supplied by the various suppliers). This level is based in inter-usability. That is, the usage of the fare media supplied by various suppliers on infrastructure deployed by various suppliers. According to Mezghani (2008), to guarantee such inter-usability, transport operators should consider the following:

- Contactless interface compatibility.
- Functional testing and certifications by independent test houses.
- Test methods for proximity cards.

Level 2.1

At level 2.1, the (contactless) smart card is used on several means of transport (such as buses, trains, taxis, etc.), operated by one transport operator, and in one location. At this level, it is important to make sure that inter-usable fare media and front-end equipment are used and that the data from all stationary computers (e.g. stops, stations, etc.) is collected at a central computer system and updated in an appropriate and secure way. Mezghani (2008) states that the resulting inter-modality required at this level, implicates an increased need for more advanced:

- Security by the usage of secure application modules.
- Sophisticated back-end systems and application software.

Level 2.2

At level 2.2, the (contactless) smart card is used on several means of transport, operated by one transport operator, and in several locations. According to Mezghani (2008), this level requires the same needs for inter-usability and inter-modality. However, since the (contactless) smart card technology has to be available for the transport of users in different locations, the transport operators also need to consider solutions for the following:

- Inter-availability of services and information.
- Reloading of ticketing media (e.g. e-purse).
- Downloading of contracts and applications.
- Key management (i.e. the distribution of keys to make the network accessible to the card holder).

Level 2.3

At level 2.3, the (contactless) smart card is used on several means of transport, operated by several independent transport operators, and in several locations. This level is based on inter-operability. That is, several transport operators cooperate as 'one' and with the same (contactless) smart card technology. On levels 1, 2.1 and 2.2, commercial agreements are normally only necessary if the fare media is to be distributed and sold through sales agents. However, according to Mezghani (2008), the focus of this level is more on commercial issues rather than on the card technology itself. As a point of start Mezghani (2008) states that, in order to guarantee interoperability, all involved transport operators need to agree on the following:

- Business rules.
- Rights and duties.
- Roles and responsibilities.
- Clearing to apportion revenues.
- Security and key management.

Additional topics that have to be taken into consideration with respect to system-wide inter-operability are card formats and system interfaces.

Level 3

Level 3 is merely the result of level 2.3. That is, an Interoperable Fare Management Structure (IFM).

This author believes that, if an IFM structure similar to that proposed in Figure 44, is implemented, the resulting data can be used to assist the proposition made herein. That is, aiding the realisation of personalised Intelligent Transport Systems (ITS) in order to achieve a multimodal transport system.

4.14 A MULTIMODAL INFORMATION SYSTEM FRAMEWORK

The transport sector, in general, is very comprehensive: a large number of stakeholders are involved in many different activities, and they coordinate their activities in different ways. However, according to Natvig *et al.* (2009), there is a growing need for systems and services to be interoperable and continuous across borders and across transport modes, with business models that meet the demands of public authorities, businesses and end users. Natvig *et al.* (2009) state that, if this need is met by implementing a common multimodal information system framework, Intelligent Transport Systems (ITS) that support intermodal transport services are more likely to be established. As a result, system interoperability, efficient information flows, coordination across transport modes, etc., can be supported by common concepts and specifications that bridge the current gaps in semantics and arrange for interoperability and efficiency.

4.14.1 A MULTIMODAL FRAMEWORK ARCHITECTURE: ARKTRANS

BACKGROUND

ARKTRANS is the Norwegian framework architecture for multimodal ITS (supporting freight and passenger transport) that is updated, further developed and managed by ITS Norway. It is the result of a multi-phase study of the transport sector conducted by scientists in informatics at SINTEF in partnership with primary stakeholders in the transport sector.

The aim of ARKTRANS is to harmonise and coordinate the transport sector into a common framework architecture that arranges for new and generic solutions. According to Natvig *et al.* (2009), ARKTRANS supports the specification and implementation of ITS applications that are in compliance with a common and holistic view of the transport sector. Moreover, it arranges for intermodal solutions and services by providing a multimodal and structured view upon the transport sector.

According to ARKTRANS's website[25], a common multimodal framework architecture will help:

- **National and international regulators** by providing them with basic guidelines and standards for messages and information flow that support the planning and execution of transport services.
- **Transport users** by providing them with similar interfaces for all transport modes in order to facilitate efficient transport itinerary planning. They will, as a result, thus receive a better service and the right information at the right time.
- **Transport service providers** to reduce costs and increase efficiency through assisting them with system integration, optimisation and re-use of information.
- **Software developers** to specify business models and solutions for transit and transport by any mode or means.
- **Authorities** by assisting them to obtain enhanced transport planning through implementing environmental- and climate policies for alternative transport options that reduce congestion, pollution and energy consumption.

CONTENT

ARKTRANS content is organised in different abstraction layers in which the transport sector is specified at different complexity levels and from different viewpoints. Refer to Figure 45 (Natvig *et al.* 2009).

[25] www.arktrans.no

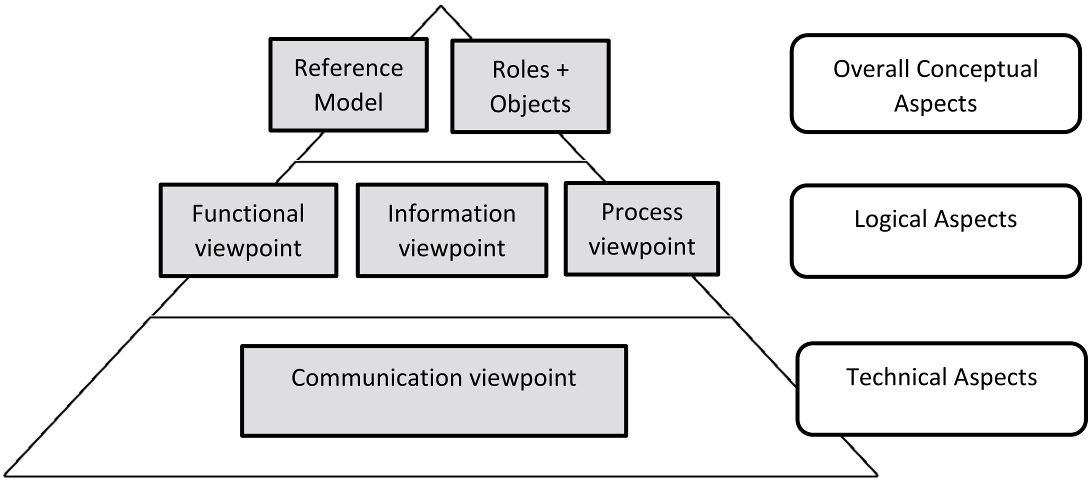


FIGURE 45: ARKTRANS CONTENT

The conceptual- and logical aspects of ARKTRANS provide a holistic view upon the responsibilities, activities and relations in the transport sector by means of a top down approach. These specifications can then be used when solutions of services are planned, developed and purchased. Moreover, the technical aspects of ARKTRANS provide specifications that arrange for the interoperability of the systems (Natvig *et al.* 2009). A more detailed explanation of the aspects in ARKTRANS content, as given in Natvig and Vennesland (2010), follows:

- The reference model divides the transport sector into manageable domains, each with specific responsibilities and concerns.
- The roles and objects define, among other things, the stakeholders in the travel information value chain and the physical entities.
- The functional viewpoint specifies the functionality related to the domains of the reference model.
- The information viewpoint specifies the information needed by the transport user as well as open service interfaces defining information exchange formats and application programming interfaces needed for the provision and acquisition of travel information and travel information services.
- The process viewpoint describes both the information acquisition process in the travel information value chain and how the transport user's travel process is supported.
- The communication viewpoint defines the technical realisation of the interfaces.

REFERENCE MODEL

The reference model provides an overall and holistic depiction of the transport sector where, the main responsibilities and focuses are addressed, but details and complexity are hidden. Refer to

Figure 46 (Natvig *et al.* 2009): note the necessary interactions among the domains depicted through the arrows therein.

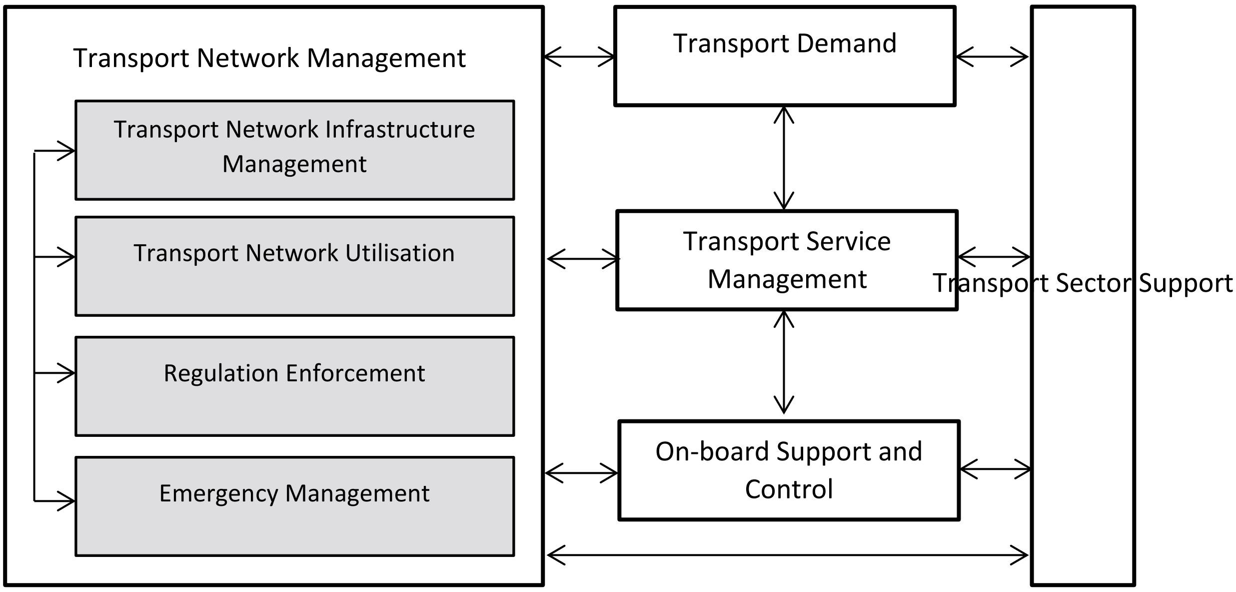


FIGURE 46: ARKTRANS REFERENCE MODEL

As can be seen in Figure 46 (Natvig *et al.* 2009), the reference model divides the transport sector into five manageable domains. In Natvig *et al.* (2009) the objectives of, and the responsibilities applicable to, each domain are defined as follows:

1. The transport demand domain supports the transport demands for both freight and passenger transport. This involves pre-trip preparation and planning as well as transport order initiation and follow-up of simple as well as more complex transport chains.
2. The transport service management domain provides transport services to the transport demand domain. This includes transport operations management and execution for both freight and passenger transport.
3. The on-board support and control domain supports the operation of transport means: e.g. navigation, adaptation to the traffic situation, and so on. On-board incident handling is also an important issue supported herein.
4. The transport network management domain provides functionality related to the transport network (e.g. roads, fairways, railroads, lanes, etc.) and the safety and efficiency of the traffic flow. This encompasses functionality that supports optimal transport network utilisation by means of traffic management, transport network infrastructure management, emergency management and regulation enforcement.
5. The transport sector support domain provides supportive services to the other domains.

DEPLOYMENT

ARKTRANS is used in several European projects, all of which have provided input to the work on the further refinement of its framework (Natvig *et al.* 2009). These are a few of the reference projects that use ARKTRANS:

- MultiRIT – Multimodal travel planning and -information services.
- INTRANS – Intelligent goods in the transport system.
- FreightWise – Support systems for co-modal freight transport.
- VIKING – ITS deployment in Northern Europe.
- ROSATTE – European road data for navigation and safety application.

MultiRit

In Natvig and Vennesland (2010), the generic ITS ARKTRANS framework has been successfully refined to support open service interfaces for the MultiRit project with the aim to facilitate information flow in the travel information value chain. Refer to Figure 47 (Natvig and Vennesland 2010).

The open interfaces defined in MultiRIT facilitate both the exchange of information and the provision of travel information services such as travel plans. As depicted in Figure 47 (Natvig and Vennesland 2010), the travel information providers will deliver travel information to providers of travel information services, and the providers of travel information services may deliver services to applications serving the transport users or to each other.

The MultiRit framework architecture thus enables third party travel information service providers to use the same processing strategies for all transport modes. As a result, the third party travel information service providers can, by combining the information from the different sources, establish value-added services. Furthermore, by allowing the end user to access information through open service interfaces, new and improved travel information services (that can support the transport user in all the phases of transit) are facilitated. Consequently, the awareness among travellers about transport alternatives and how public transport can be combined with walking, cycling and use of private cars, may be increased (Natvig and Vennesland 2010).

In Natvig and Vennesland (2010), a pilot of this proposed MultiRit multimodal travel planner was implemented, and the results obtained is stated to provide valuable input to the realisation of a national travel planner for Norway.

4.14.2 NATIONAL ITS ARCHITECTURE FOR SOUTH AFRICA

As mentioned previously, South Africa has no national Intelligent Transport Systems (ITS) architecture. However, in SANRAL (2010), an ITS implementation guideline, as part of the ITS standards development (i.e. SABS: South African Bureau of Standards), is given. This guideline identifies and states the minimum technical- and operational requirements that an ITS deployment needs to conform and adhere to. More specifically, a guideline to the procurement of a national ITS architecture, with integrated supporting systems software, and the deployment thereof in Gauteng, Kwazulu-Natal and the Western Cape, is given.

The guideline given in SANRAL (2010), distinguishes between a list of regional- and a list of national functions. The list of regional functions encompasses the implementation requirements relating to Advanced Traffic Management Systems (ATMS) such as Freeway Management Systems (FMS) and Incident Management Systems (IMS); whereas the list of national functions focuses on the information side of ITS. That is, functions like Advanced Traveller Information Services (ATIS), but only in the context of the Private Vehicle Network (PVN). More specifically, the implementation requirements for aspects such as data archiving, data aggregation and information dissemination, through a web-based route planner, are stipulated.

This document clearly spurs and underlines a revolution towards multimodal transport. However, in order to achieve an integrated and interoperable transport system, a multimodal framework architecture (with its subsequent travel information value chain), needs to be stipulated. It is therefore recommended that ARKTRANS framework architecture for multimodal ITS be further researched. It is believed that, by benchmarking on their standards and implementation approach, a similar travel information value chain to that of Figure 47 (Natvig and Vennesland 2010), may be developed for South Africa. And with the realisation of such a multimodal framework architecture, the proposition made herein will be spurred on.

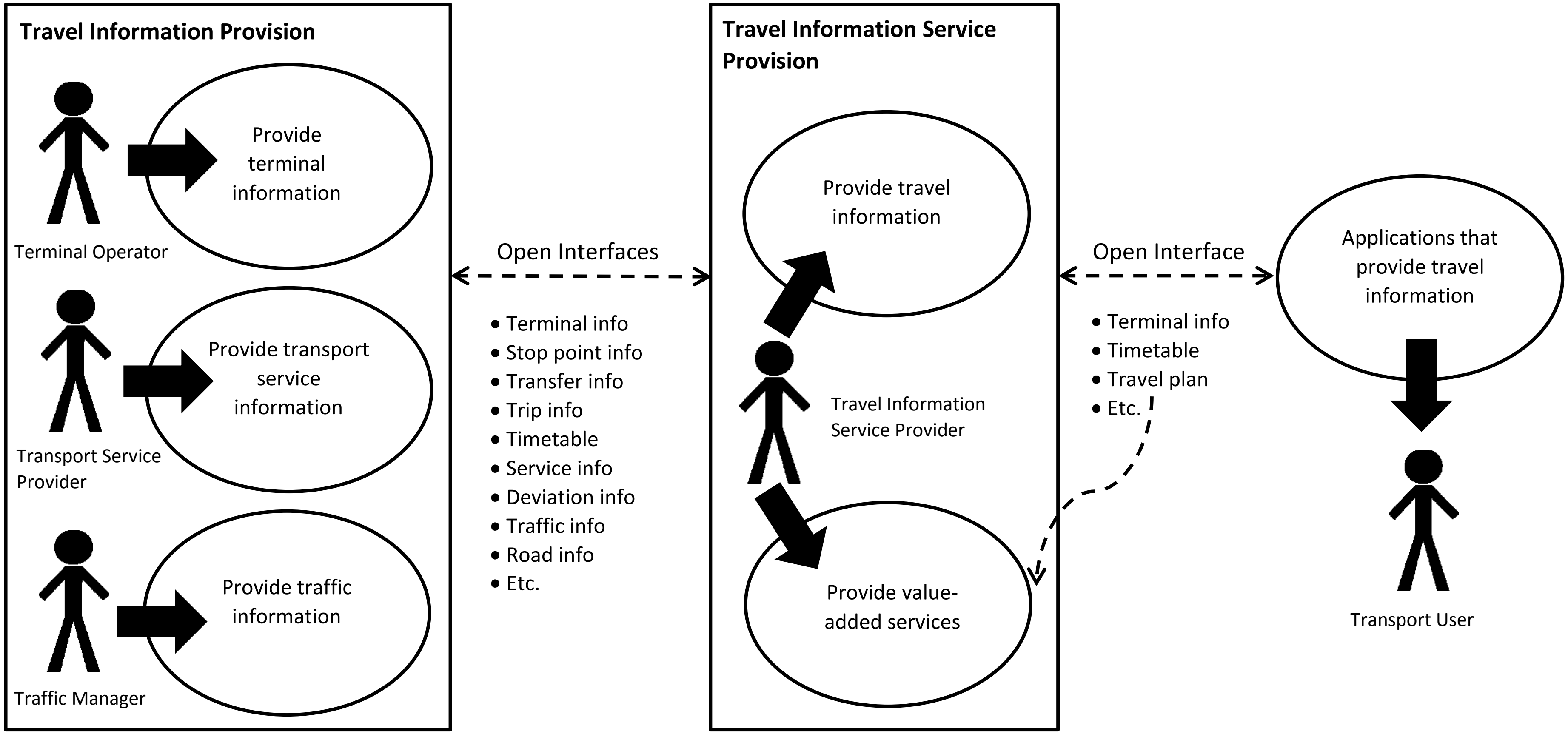


FIGURE 47: THE MULTIRIT TRAVEL INFORMATION VALUE CHAIN

4.15 THE STEPS TOWARDS A MULTIMODAL PLATFORM

From the aforementioned researched conducted, the enormity and complexity of the proposition made herein, become evident.

As mentioned previously, the main focus areas for implementing a multimodal platform are: 1) the multimodal transport network and the design and modelling thereof, 2) the role of Intelligent Transport Systems (ITS) in achieving a multimodal platform, 3) the need for and the design criteria of a (centralised) database, and 4) the need for and the travel information requirements of a multimodal Journey Planner (JP). The sequential steps, deducted from the aforementioned researched conducted, required in achieving a multimodal platform, can be seen in Table 8. Step 1 to step 10 relate to focus area one, step 11 and step 12 to focus area two, step 13 to step 23 to focus area three, and lastly, step 24 to step 29 to focus area four.

TABLE 8: THE PROPOSED GENERIC FRAMEWORK FOR A MULTIMODAL PLATFORM DEVELOPMENT

STEPS	ASPECTS	CONSIDERATIONS	FOUNDATION
1	Mode Selection	MyCiti, Metrorail, GABS, privately owned vehicles, (minibus taxis, metered-taxis)	
2	The Multimodal Transport Network Design	Supernetwork, Hierarchical Network	Graph Theory
3	Modelling User Constraints	Deterministic Finite State Automaton, Nondeterministic Finite State Automaton	Finite State Automata, Language Theory
4	The Networks	Private Vehicle Network, Public Transport Network, Foot (Pedestrian) Network	
5	The Graph Models	The Condensed Model, The Time Expanded Model, The Time Dependent Model	Time Independent, Time Dependent
6	Vertex- and Edge Type	Physical-, Event-, Transfer- and Route vertices; Physical-, Transfer- and Trip sequence Edges	
7	Weight Metric for Optimisation	Travel Time, Geographical Distance (Euclidean Method, Great Circle Method), Generalised-Cost approach	
8	Merge- and Link Operations	Linear Search, K-D trees	Nearest Neighbour Problem
9	Routing Algorithm	Shortest Path Problem (SPP), Many-to-Many SPP, One-to-All SPP, All-pairs SPP	Earliest Arrival Problem, Dijkstra's Regular Language Constrained SPP

STEPS	ASPECTS	CONSIDERATIONS	FOUNDATION
10	Network Size	Bi-directional Search, Goal-directed Search, Pre-processing Contraction Hierarchies	Speed-up Techniques
11	Advanced Traffic Management Systems	Freeway Management Systems, Arterial Management Systems, Urban Traffic Control	Intelligent Transport Systems (ITS)
12	Advanced Public Transport Systems	Automated Vehicle Location, Electronic Fare Payment (Automated Fare Collection and Interoperable Fare Management), Advanced Traveller Information Systems	Intelligent Transport Systems
13	Data Repository Type	Database, Data Warehouse	
14	The Database Management System	Online Transaction Processing, Operational Data Store, Online Analytical Processing, Data Warehouse/Data Mart	
15	Sharing the Database	Security, Authentication and Access to the Database	The Database Management System
16	Data Models	High-level, Low-level, Representational (i.e. Legacy and Relational)	
17	Defining the Relational Database	Domains, Attributes, Tuples, Relations, Relation Schemas, Relational Database Schema and – State	
18	Managing the Relational Database	Relational Database Schema Constraints: Domain constraints, constraints on NULL values, Primary key constraints and Integrity constraints (i.e. Entity and Referential)	Relational Database Management
19	Database Type	Microsoft SQL Server, Microsoft Access, Oracle	
20	Data Standards	Data Type, Data Structure, Naming Conventions	Normalisation Principles
21	Server Type	Database, Web Graphic User Interface (GUI)	User Interface
22	Server Architecture	2-Tier Client-Server, 3-Tier Client Server	
23	Network Type	Hierarchical, Star, Ring, Bus	Network Topologies
24	The Value of Information	The Information Quality Attributes, The Information Valuator, The Information Service Value Chain	Information Theory, Value Theory, Utility Theory

STEPS	ASPECTS	CONSIDERATIONS	FOUNDATION
25	Passenger Travel Information Needs	Pre-trip, on-trip, end-trip phase	
26	Information Services deemed Important by the Travellers	JP criteria: 1) transport modes covered 2) sufficiency of static journey information provided 3) geographical coverage 4) quality of information display 5) sufficiency of itineraries offered 6) real time information capability 7) sufficiency of on-trip information provision 8) ticket booking capability 9) the means for information service accessibility	The Value of Information
27	Travellers' Choice Behaviour on Information Service Media	Personal Attributes, Information Attributes, Usage of Internet and Mobile Phone	
28	The provision of personalised Information	Automated Fare Collection, RFID	Personalised ITS
29	A Multimodal Framework Architecture	Overall Conceptual Aspects, Logical Aspects, Conceptual Aspects	

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5.1 INTRODUCTION

In this section, the sequential steps identified in Table 8, are used as a point of reference for implementing a multimodal platform, with the logical application of the generic (sequential) framework developed tested on the CoCT's land transport networks.

5.2 THE FOCUS AREA

5.2.1 THE TRANSPORT MODES CONSIDERED

The transport modes considered in promoting a multimodal transport network may be seen in Figure 48.

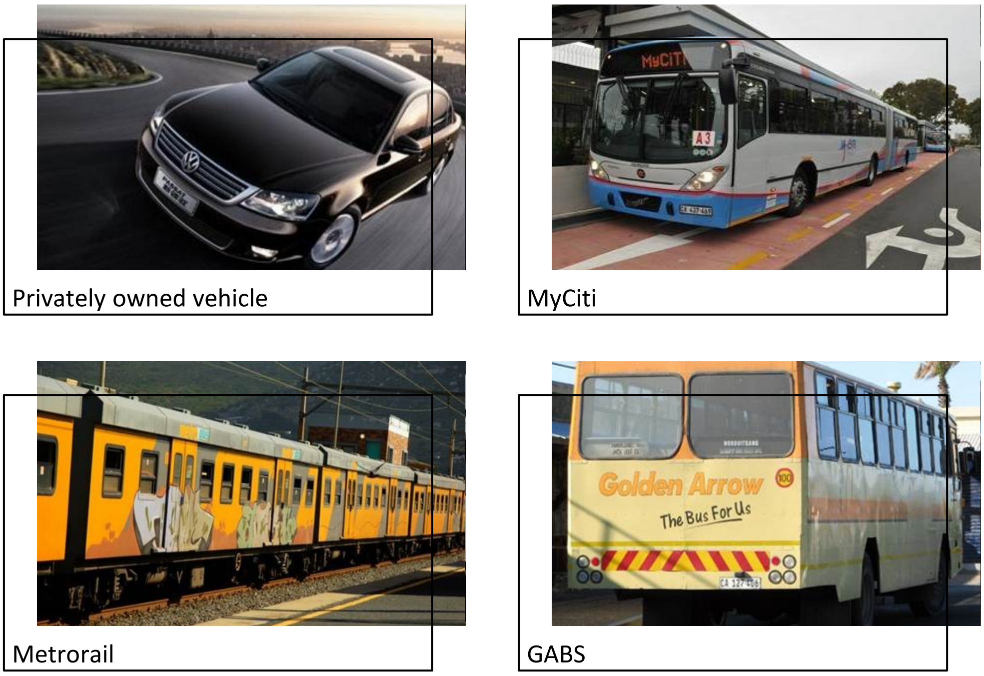

FIGURE 48: THE TRANSPORT MODES CONSIDERED

5.2.2 THE CORRIDOR SELECTED

In order to cater for all the transport modes considered herein, the corridor selected is from Blouberg to Durbanville via Cape Town's Central Business District (CBD), more specifically, the Civic Centre. (This corridor may be expanded in the future, if for example, the MyCiti network expands.)

The MyCiti Civic Centre stop, in Hertzog Boulevard, is centrally located in Cape Town and is the hub of all MyCiti services; connecting the Gardens - Civic - Waterfront service to Table View. Moreover, there are also convenient connections around the Civic Centre stop to suburban- and long-distance rail, local- and inter-city bus services, as well as minibus- and metered-taxis. Refer to Table 9 (MyCiti 2010).

TABLE 9: THE MYCITI CONNECTIONS

Suburban rail network	Cape Town rail station
Long-distance rail network	Cape Town rail station
Suburban buses	Grand Parade
Long-distance buses	Between rail station and Civic Centre
Metered-taxis	Ranks in Adderley Street
Minibus taxis	Rail station deck

Based on the corridor selected, MyCiti's trunk route, Metrorail's northern line, the surrounding Golden Arrow Bus Services' (GABS) stops, as well as the applicable Variable Message Signs (VMS) and Closed Circuit Television (CCTV) cameras, will be considered.

The coordinates of the stops relating to the MyCiti's trunk route and the stations relating to Metrorail's northern line were computed from Google Maps. And the coordinates of the surrounding GABS' stops were obtained from Derick Meyer, GABS Schedule Manager. Table 10, Table 11 and Table 12 depict these coordinates.

TABLE 10: THE STOP COORDINATES OF THE MYCITI TRUNK ROUTE

Latitude	Longitude	MyCiti Stop Name
18.42836	-33.9204	Civic Centre stop
18.44635	-33.9229	Woodstock stop
18.46712	-33.9179	Paarden Eiland stop
18.46961	-33.9151	Neptune stop
18.47244	-33.9119	Section stop
18.47523	-33.9075	Vrystaat stop
18.48106	-33.9012	Zoarvlei stop
18.48484	-33.8912	Lagoon Beach stop
18.49068	-33.883	Woodbridge stop
18.49411	-33.8718	Milnerton stop
18.49995	-33.8616	Racecourse stop
18.49583	-33.8533	Sunset Beach stop
18.48862	-33.8237	Table View stop

All of the coordinates were saved as Comma Separated Values (CSV) and converted to Keyhole Mark-up Language (KML) format in order to be recognised by Google Earth (GE). The CSV files of these coordinates can be viewed on the attached CD, with their coordinates visually represented in

Figure 49, Figure 50 and Figure 51. The grids in Figure 49, Figure 50, Figure 51, Figure 52 and Figure 53 were drawn using the GE plug-in program GE Path.

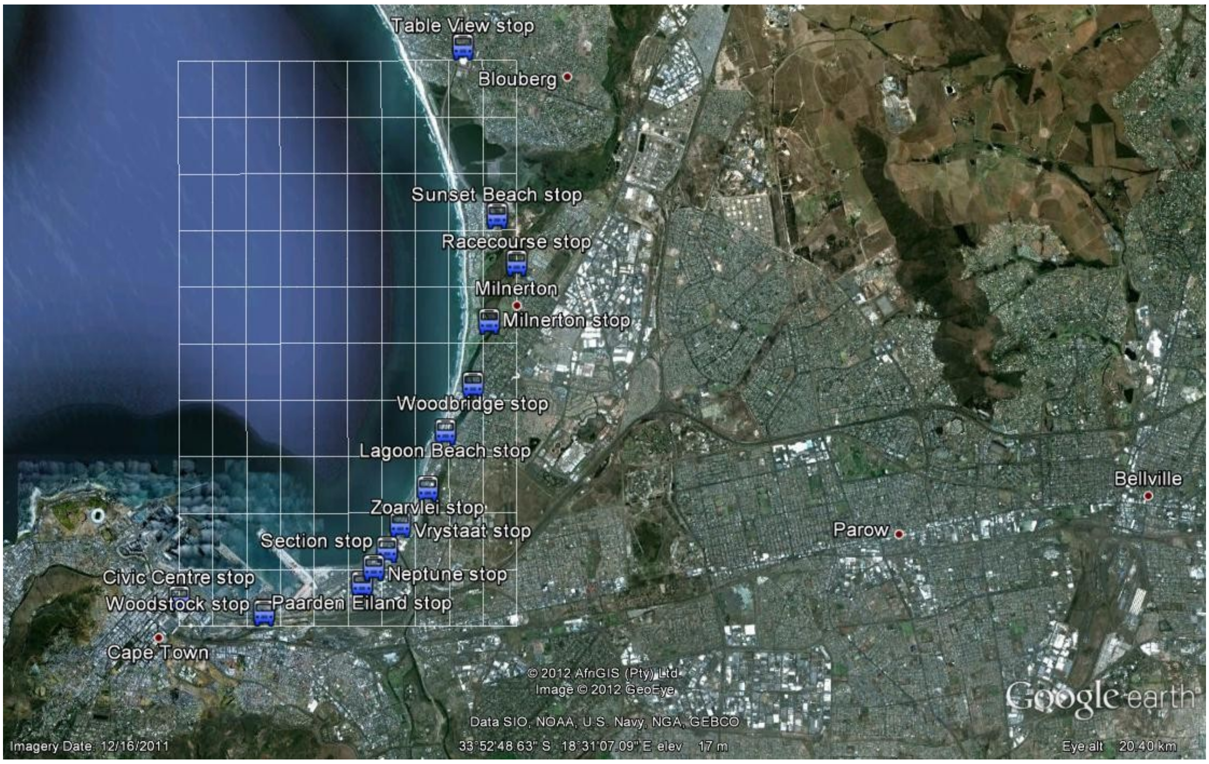

FIGURE 49: GE OF MYCITI TRUNK ROUTE

TABLE 11: THE STATION COORDINATES OF THE METRORAIL NORTHERN LINE

Latitude	Longitude	Metrorail Station Name
18.68825	-33.881	Brackenfell station
18.65709	-33.9044	Stikland station
18.62834	-33.9065	Bellville station
18.60125	-33.9075	Tygerberg station
18.58622	-33.9097	Parow station
18.56921	-33.9106	Elsies River station
18.55857	-33.9113	Vasco station
18.54739	-33.9145	Goodwood station
18.53259	-33.9189	Thornton station
18.51477	-33.9211	Mutual station
18.50735	-33.9221	Woltemade station
18.48707	-33.9247	Maitland station
18.47884	-33.9257	Koeberg station
18.46455	-33.9272	Salt River station
18.44586	-33.9253	Woodstock station
18.42507	-33.9221	Cape Town station

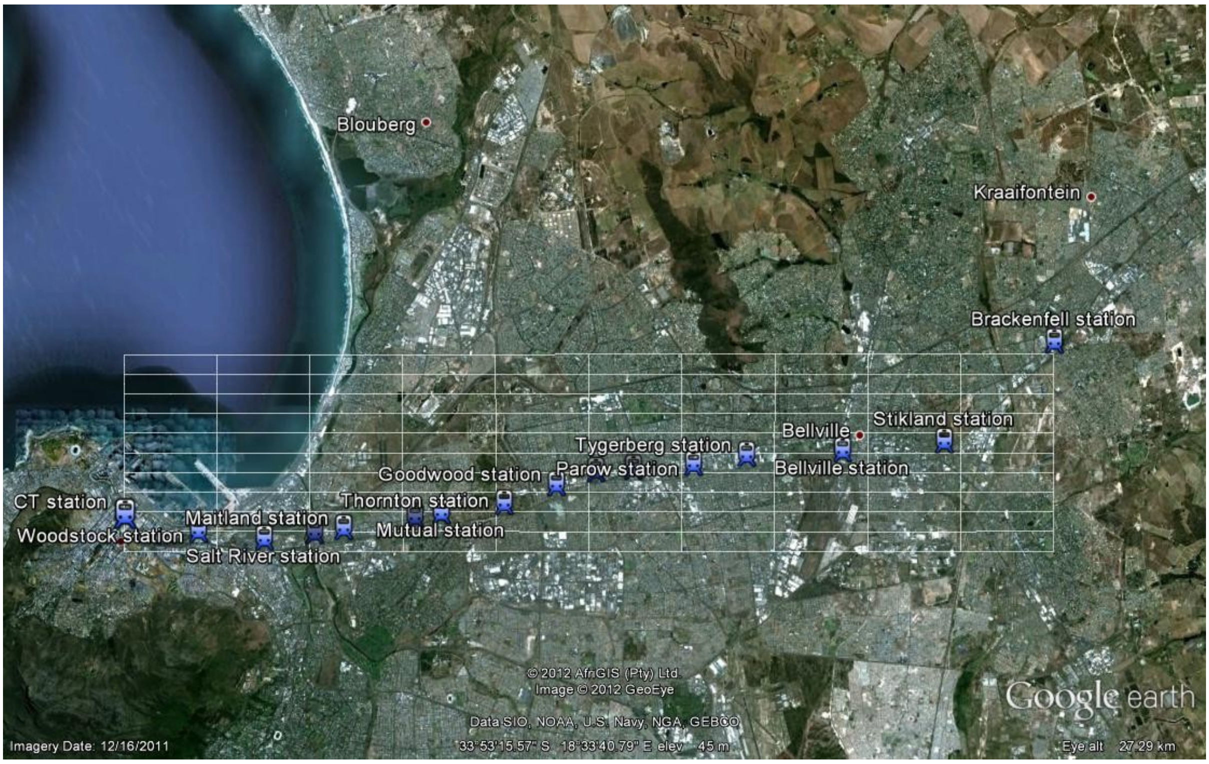

FIGURE 50: GE OF METRORAIL NORTHERN LINE

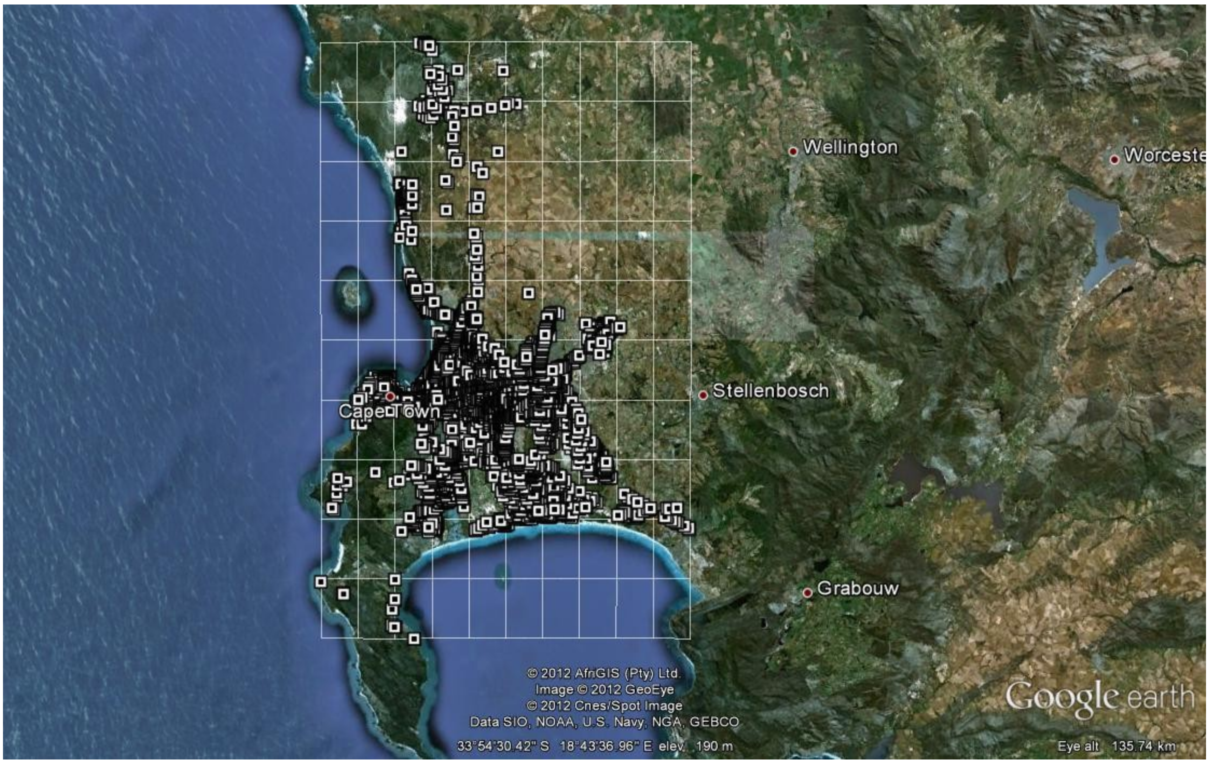

FIGURE 51: GE OF WESTERN CAPE GABS STOPS

In Figure 51, only approximately 3100 of the 5500 stops obtained were plotted. As can be seen in this figure, the number of GABS stops is clearly very large. As a result, the usage of the grids (as seen in Figure 52 and Figure 53) was needed to filter the number of GABS' stops to thus determine only the applicable GABS stops relating to the corridor selected. In Figure 52 the overlaid grids can be seen and in Figure 53, the hence following corridor selected, can be viewed.

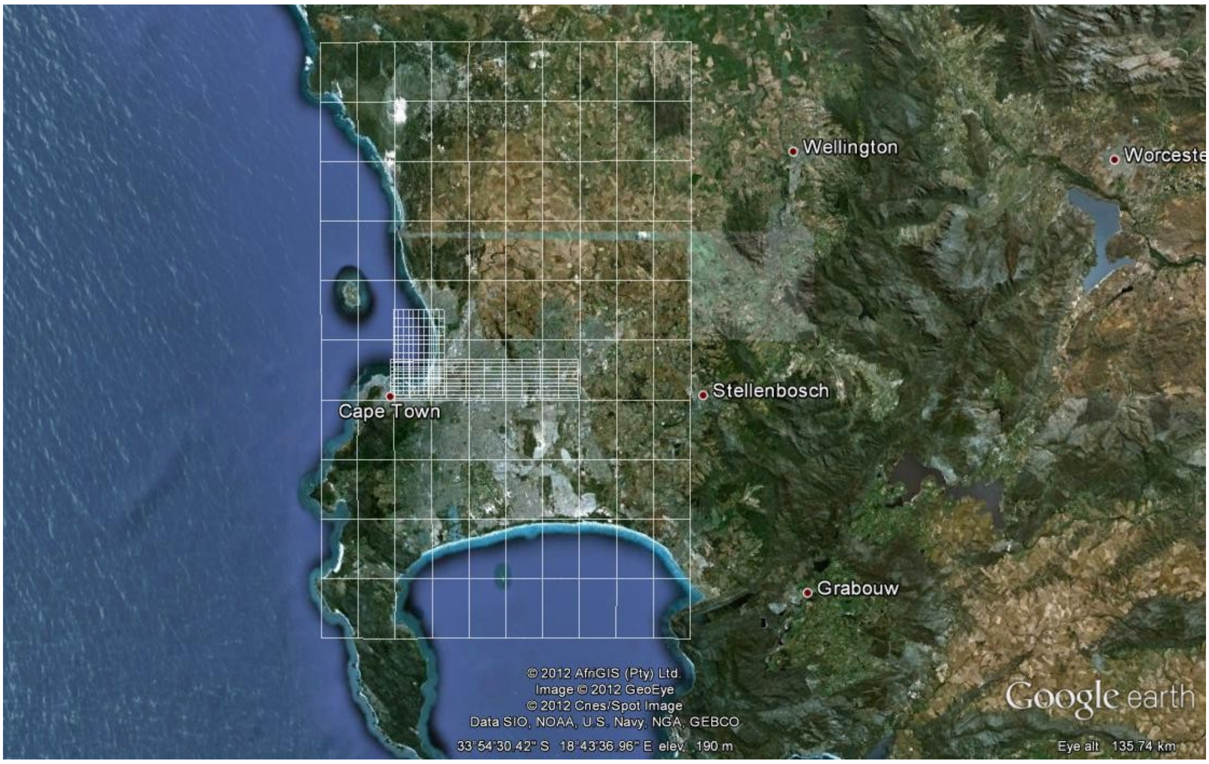

FIGURE 52: GRIDS OVERLAID

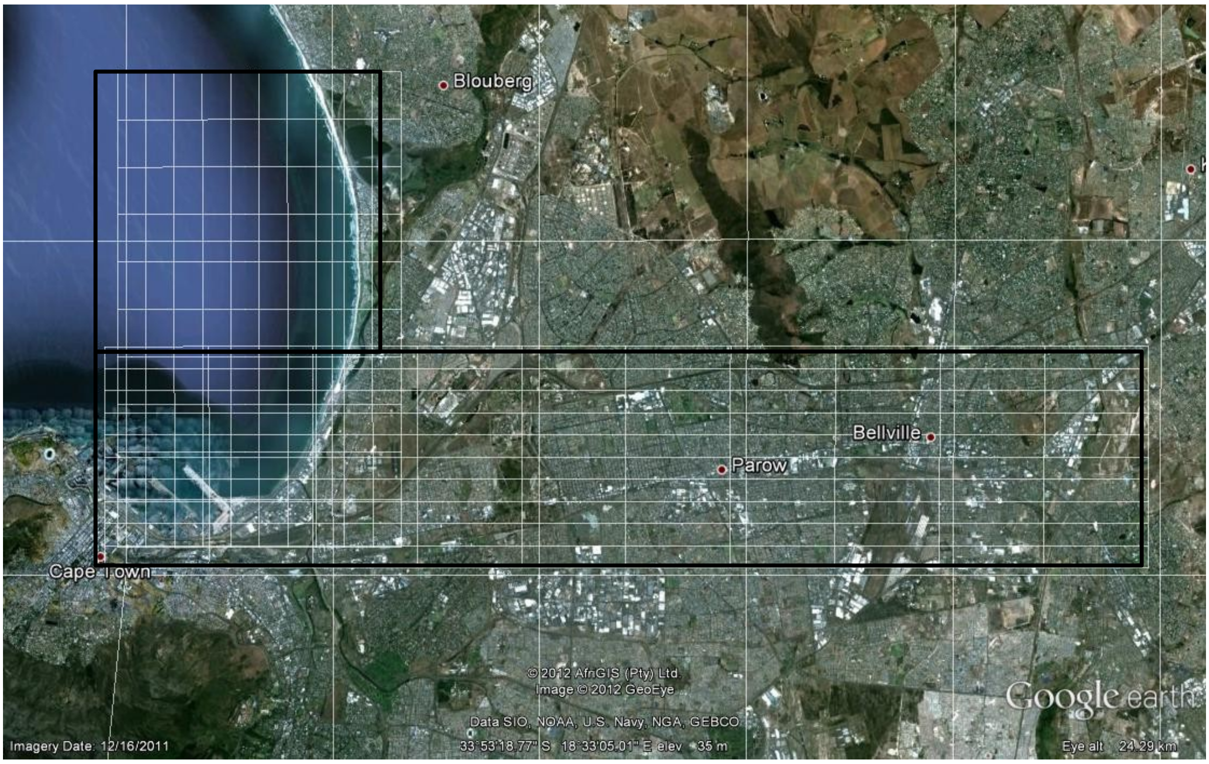

FIGURE 53: THE CORRIDOR SELECTED

In order to filter the GABS stops even more, it was decided to only focus on the main stops in the corridor selected. These stops were determined from Figure 54: Metrorail's Transport Route Guide.

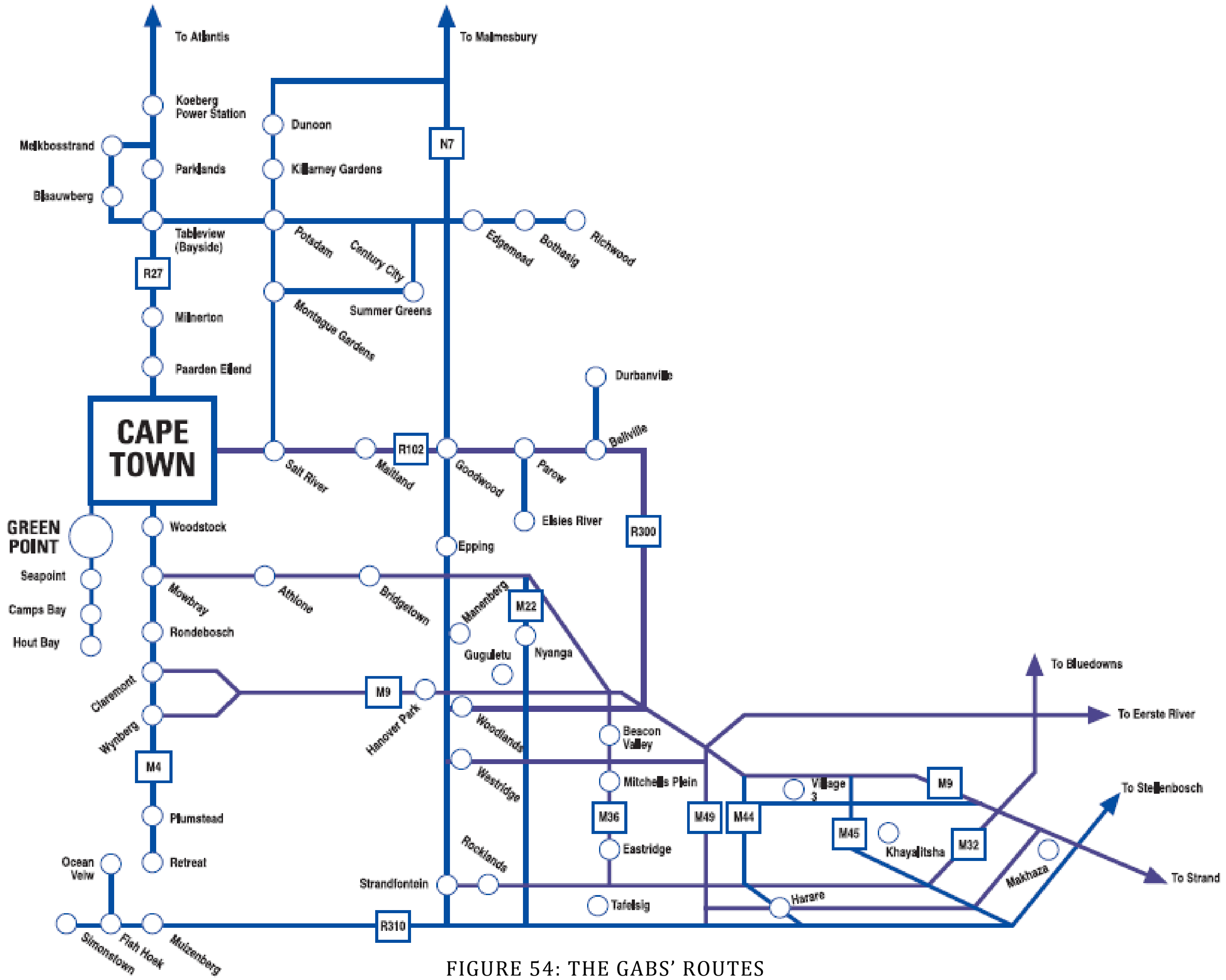

FIGURE 54: THE GABS' ROUTES

Based on Figure 54, the correlating GABS' stops chosen and the coordinates thereof can be seen in Table 12 and Figure 55.

TABLE 12: THE COORDINATES OF THE APPLICABLE GABS STOPS

Latitude	Longitude	GABS Stop Name
18.440233	-33.675833	Koeberg Power Station
18.440233	-33.730817	Melkbosstrand
18.457400	-33.789467	Blouberg
18.495950	-33.816000	Parklands
18.490783	-33.825350	Table View (Bayside)
18.494267	-33.889300	Milnerton
18.477483	-33.904650	Paarden Eiland
18.424717	-33.923883	Cape Town
18.448100	-33.928800	Woodstock
18.455417	-33.931050	Salt River
18.520217	-33.915250	Maitland
18.548783	-33.912183	Goodwood
18.600750	-33.907000	Parow
18.568267	-33.911583	Elsies River
18.630567	-33.904283	Bellville
18.651567	-33.827883	Durbanville

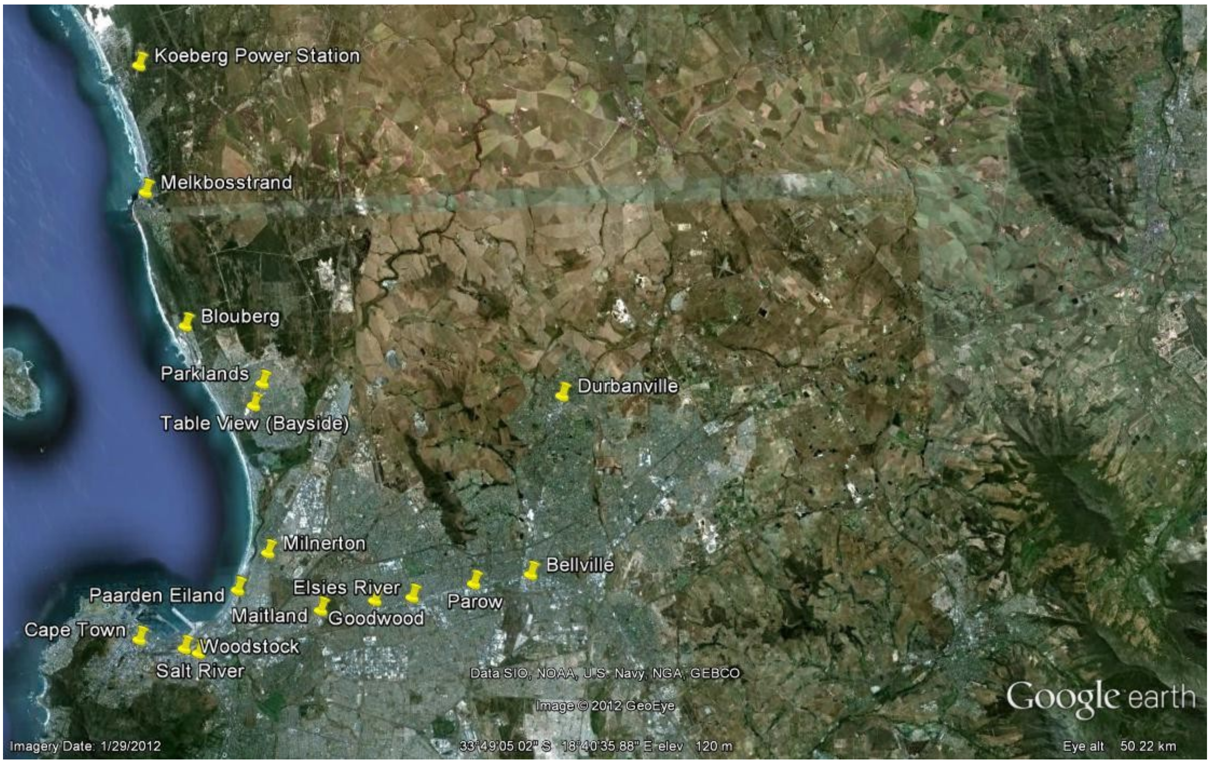

FIGURE 55: GE OF THE APPLICABLE GABS STOPS

Lastly, in Figure 56, the camera coverage on the freeways is represented through the highlighted areas. These areas have VMS and CCTV cameras and are being monitored by the

City's Transport Management Centre (TMC). This data was given to this author by courtesy of SANRAL.

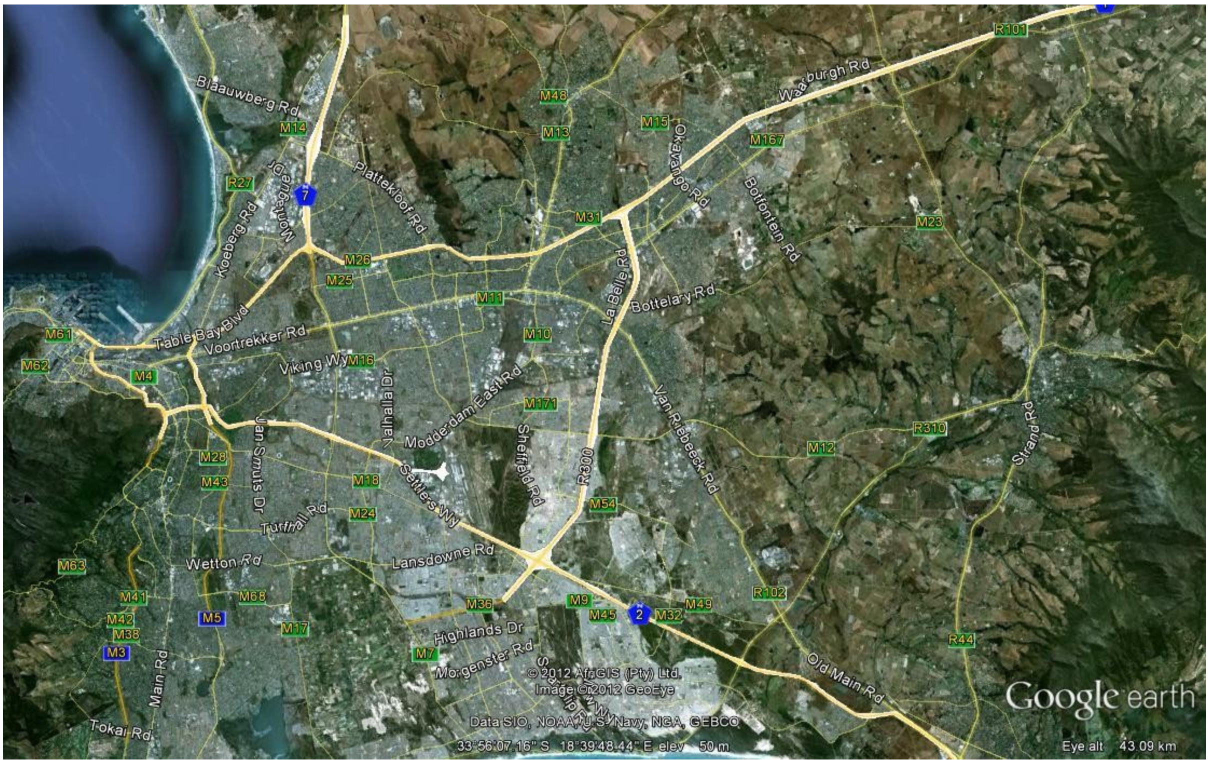

FIGURE 56: CAMERA COVERAGE ON FREEWAYS

As can be seen in Figure 56, the freeways that are being monitored and that are applicable to the corridor selected are: the N1, the N2, the N7 and the R300.

5.3 MULTIMODAL ROUTING

5.3.1 MODELLING CONSIDERATIONS

THE NETWORKS CONSIDERED

Even though the Private Vehicle Network (PVN) was taken into consideration with the selection of the corridor, only the Public Transport Network (PTN) was utilised in modelling the multimodal transport network. That is: the MyCiti-, Metrorail- and GABS network.

REASONING

The modelling of the PVN (i.e. the intersections as vertices and the road segments as edges) was deemed to be out of scope for the construct of this research project due to difficulty with obtaining the necessary data. Following from this, this author was severely set back with time and therefore the analysis of the position-data relating to the road network (i.e. the applicable freeways) would have been too time consuming. Furthermore, this author also did not have the appropriate GIS software at her disposal and would thus have needed to make arrangements for the attainment thereof.

THE WEIGHTS FOR THE SHORTEST PATH CALCULATION

In determining the shortest path, two weights were considered. That is, travel distance and travel time.

TRAVEL DISTANCE

In computing the travel distance, two methods were considered. That is, the Euclidean Method and the Great Circle Method. A discussion of each follows.

The Euclidean Method

The Euclidean Method calculates the straight line distance between two points similar to how one would measure the distance with a ruler. It is given by the Pythagorean Formula shown in Equation 6 (Wikipedia 2012).

EQUATION 6: THE EUCLIDEAN DISTANCE

$$d(p,q) = \sqrt{(p_1 - q_1)^2 + (p_2 - q_2)^2}$$

In this equation, d represents the distance in the same units as that utilized in p and q; p represents point 1 and q represents point 2, where the 1 and 2 correlates to the points' x- and y coordinates.

The Great Circle Method

The Great Circle Method calculates the shortest distance between any two points on the surface of a sphere (as opposed to Equation 6 that computes the distance by going through the interior of the sphere). In this non-Euclidean geometry, the straight lines are thus replaced with geodesics. Geodesics on the sphere are the great circles. That is, the circles on the sphere whose centres are coincident with the centre of the sphere. Refer to Equation 7 (Wikipedia 2012).

EQUATION 7: THE GREAT CIRCLE DISTANCE

$$d = r\Delta\sigma$$

In this equation, d represents the distance in km; r represents the radius of the earth taken as 6371 km, and $\Delta\sigma$ the spherical distance. Refer to Equation 8 (Wikipedia 2012).

EQUATION 8: THE SPHERICAL DISTANCE

$$\Delta\sigma = arccos(sin\Phi s * sin\Phi f + cos\Phi s * cos\Phi f * cos\Delta\lambda)$$

In this equation, Φ represents the geographical latitude and λ the geographical longitude of two points (a base "standpoint" and a destination "fore-point") and $\Delta\lambda$ the difference of the two points' longitudes.

The Method chosen

As mentioned previously, because the x- and y coordinates are in a geographical format (i.e. latitude and longitude), using the Euclidean Method to compute the distance will result in insufficient answers. Therefore, because the Great Circle Method takes the contour of the earth into account by using geodesics, it was chosen over the Euclidean Method.

TRAVEL TIME

For the purpose of this research project, the travel time was computed independently of the time of the day and the day of the week. However, the direction of travel was taken into account. This will be explained in the following sections.

The Journey Times on MyCiti's Trunk Route

For the MyCiti trunk route, the time between consecutive stops was obtained from MyCiti's schedule. Furthermore, according to MyCiti's schedule, this time is the same regardless if the user starts his/her journey at the Civic Centre- or at the Table View stop. Refer to Figure 57.

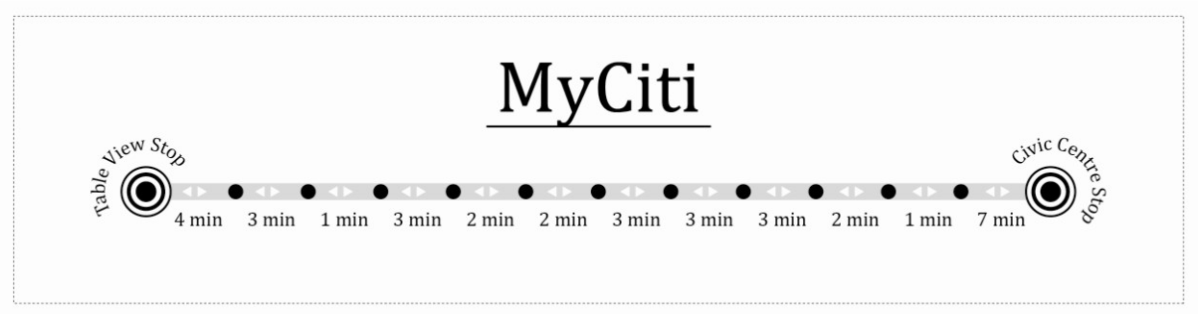

FIGURE 57: MYCITI TRUNK ROUTE JOURNEY TIMES

The Journey Times on Metrorail's Northern Line

The time between consecutive stations, correlating to Metrorail's northern line, was also obtained from Metrorail's schedule. However, according to Metrorail's schedule, this time differs according to the travel direction. That is, whether a user starts his/her route at the Cape Town- or Brackenfell station. Refer to Figure 58 and Figure 59.

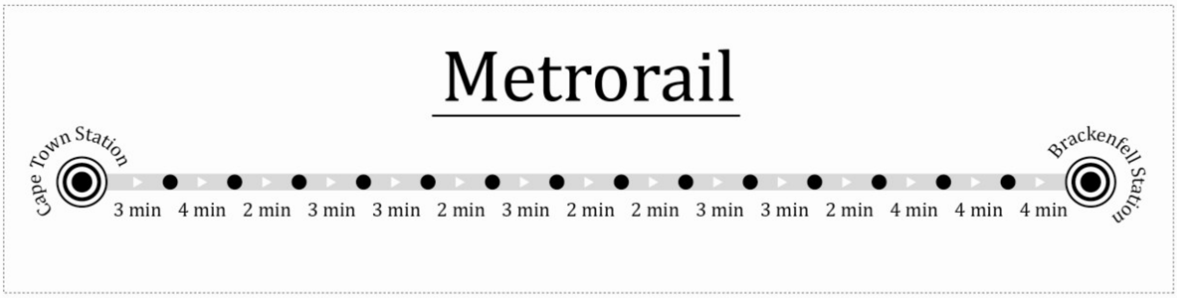

FIGURE 58: METRORAIL NORTHERN LINE DIRECTION 1 JOURNEY TIMES

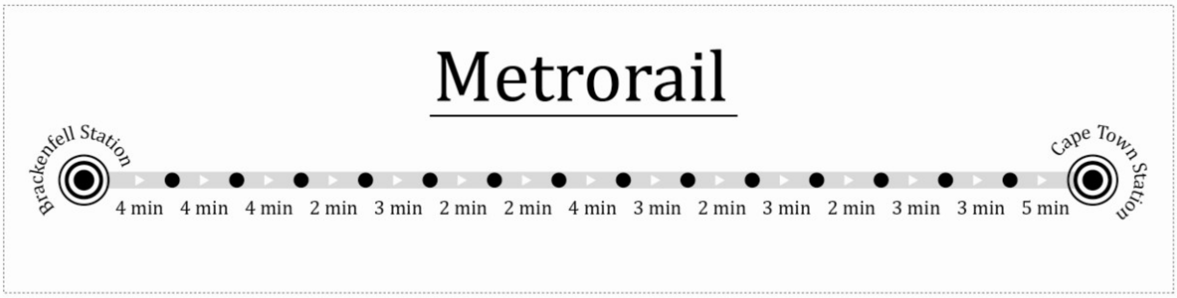

FIGURE 59: METRORAIL NORTHERN LINE DIRECTION 2 JOURNEY TIMES

The Journey Times on the applicable GABS' stops

For the applicable GABS' stops, the (rounded-up) time between consecutive stops was calculated by using the Great Circle distance of the respective road segment and a travel speed of 50km/h. Furthermore, since the allowed travel speed in urban areas in South Africa is 60km/h, and if one encompasses lost time at signal interchanges, it is believed that 50km/h is an appropriate approximate of the average travel speed of a bus in the GABS' fleet. Refer to Figure 60.

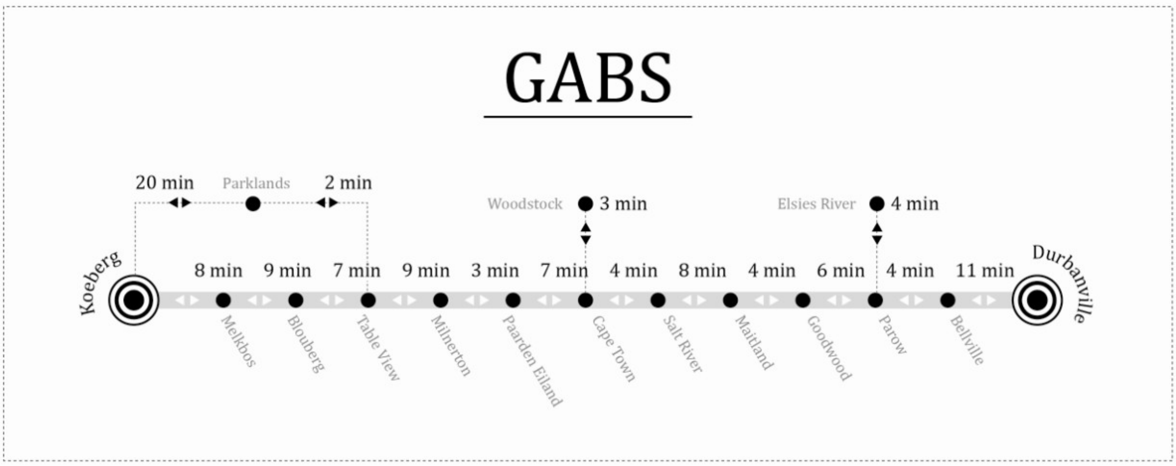

FIGURE 60: THE JOURNEY TIMES ON THE APPLICABLE GABS' STOPS

Lastly, it is assumed that all transfers will be conducted by walking from one mode to another mode, at an average speed of 4.5 km/h. Therefore, the transfer time between modes was calculated by using this assumed average walking speed and the corresponding Great Circle distance of the transfer link.

(Figure 57, Figure 58, Figure 59 and Figure 60 were drawn by Lovia Delport: Graphic Designer.)

5.3.2 IMPLEMENTING DIJKSTRA'S ALGORITHM

Dijkstra's Algorithm is programmed by this author in Microsoft Excel utilising both standard Excel functions and Excel's Visual Basic for Applications (VBA). The VBA code of the program can be viewed in Section 11.1 and the program itself can be found on the attached CD. The following websites were used in aiding this author with the algorithm's implementation:

- http://www.pcreview.co.uk
- http://www.allexperts.com
- http://www.justanswer.com
- http://www.ozgrid.com
- http://www.stackoverflow.com
- http://www.techguy.org
- http://www.support.microsoft.com
- http://www.teachexcel.com
- http://www.excel.bigresource.com
- http://www.vbaexpress.com
- http://www.codeforge.com

5.3.3 PROGRAM EXPLANATION

SHEET 1: SUPERNETWORK

As mentioned previously, if the multimodal network is computed as a hierarchical (multi-level) network, the design thereof is unnecessarily complicated. However, if the multimodal transport network is modelled as a single-level supernetwork, the complexity of the design problem is considerably reduced. Sheet 1 of the program therefore depicts the supernetwork utilised in Dijkstra's Shortest Path Problem (SPP).

In Figure 61, the 13 stops of the MyCiti trunk route, the 16 (main) stops of the GABS network relating to the corridor selected, and the 16 stations of the Metrorail northern line, are depicted through the circles representing vertices. The lines connecting the circles are the edges that represent traversing between these stops/stations. No arrows were drawn here, since traversing in both directions are allowed. The dotted lines represent the link (transfer) edges that connect the unimodal networks into a multimodal supernetwork. The vertices where transfers are allowed were solely chosen based on their closeness to each other (i.e. Nearest Neighbour Problem) since, as mentioned previously, it is assumed that transferring from one mode to another mode will be conducted by walking. As can be seen in this figure, the maximum transfer distance (computed by the Great Circle Method) is 0.673 km. The idea was that the transfer distance, in real world terms, should not be much more than 1 km.

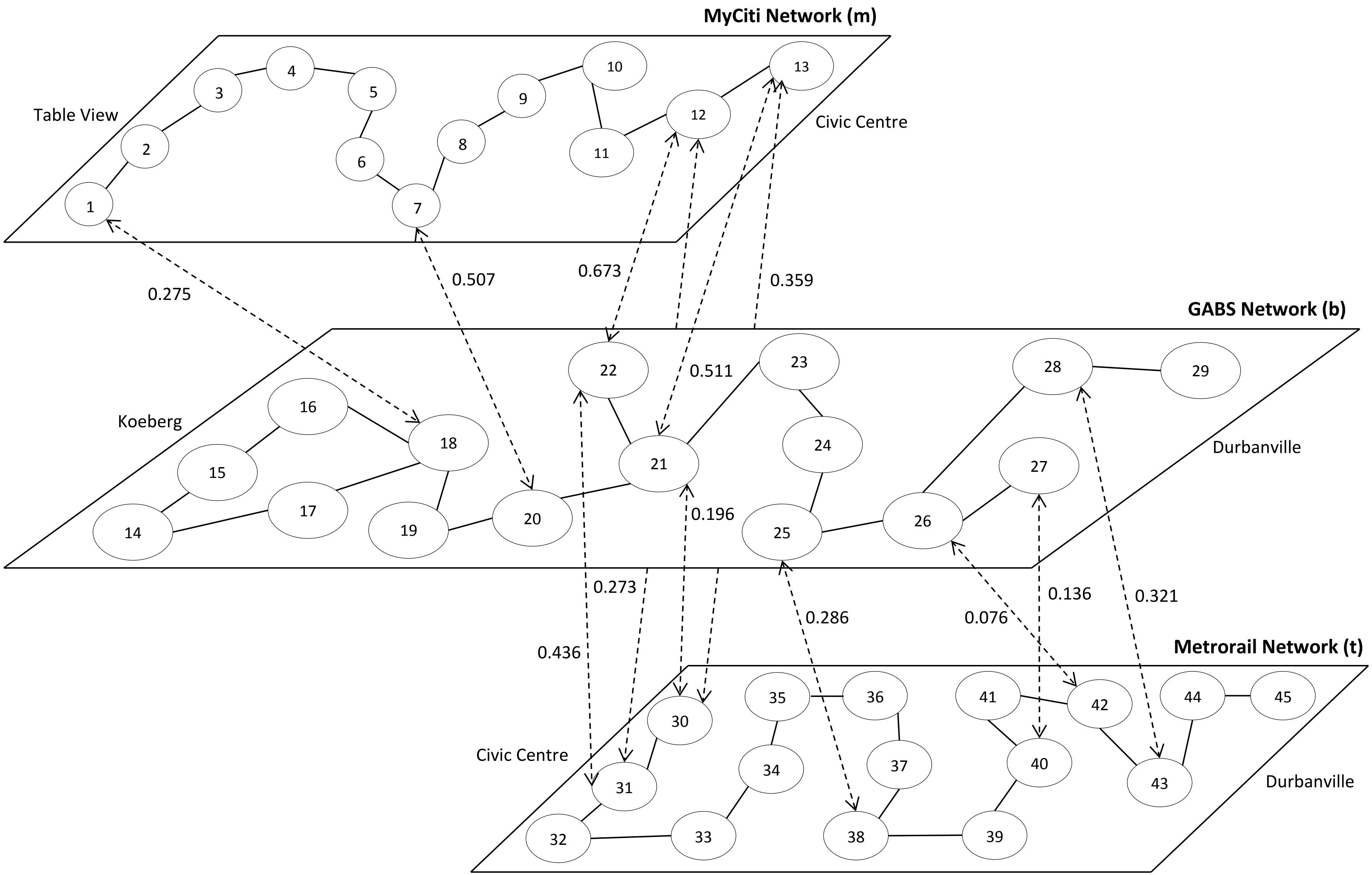

FIGURE 61: THE PUBLIC TRANSPORT SUPERNETWORK

SHEET 2: COORDINATES

Sheet 2 contains the position (i.e. the latitude (φ) and longitude (λ)) of each vertex, both in degrees and in radians. The data of this sheet is the input to Sheet 3, where the corresponding distance matrix is computed. Throughout this program, as can be seen in Figure 61, each stop/station is given a number to simplify the computational effort required. In Table 13 the number given to each vertex can be seen.

TABLE 13: VERTEX NUMBER FOR MODELLING OF SUPERNETWORK

Vertex Number	Stop/Station Name	Mode Type
1	Table View stop	MyCiti
2	Sunset Beach stop	MyCiti
3	Racecourse stop	MyCiti
4	Milnerton stop	MyCiti
5	Woodbridge stop	MyCiti
6	Lagoon Beach stop	MyCiti
7	Zoarvlei stop	MyCiti
8	Vrystaat stop	MyCiti
9	Section stop	MyCiti
10	Neptune stop	MyCiti
11	Paarden Eiland stop	MyCiti
12	Woodstock stop	MyCiti
13	Civic Centre stop	MyCiti
14	Koeberg Power Station	GABS
15	Melkbosstrand	GABS
16	Blouberg	GABS
17	Parklands	GABS
18	Table View (Bayside)	GABS
19	Milnerton	GABS
20	Paarden Eiland	GABS
21	Cape Town	GABS
22	Woodstock	GABS
23	Salt River	GABS
24	Maitland	GABS
25	Goodwood	GABS
26	Parow	GABS
27	Elsies River	GABS
28	Bellville	GABS
29	Durbanville	GABS
30	Cape Town station	Metrorail
31	Woodstock station	Metrorail
32	Salt River station	Metrorail
33	Koeberg Road station	Metrorail
34	Maitland station	Metrorail
35	Woltemade station	Metrorail
36	Mutual station	Metrorail
37	Thornton station	Metrorail
38	Goodwood station	Metrorail

Vertex Number	Stop/Station Name	Mode Type
39	Vasco station	Metrorail
40	Elsies River station	Metrorail
41	Parow station	Metrorail
42	Tygerberg station	Metrorail
43	Bellville station	Metrorail
44	Stikland station	Metrorail
45	Brackenfell station	Metrorail

SHEET 3: DISTANCE MATRIX

In Sheet 3, a distance matrix is utilised to calculate the distance between each vertex pair with aid of the Great Circle Method.

As mentioned previously, it is assumed that the earth has a radius of 6371 km. Furthermore, in this sheet it is also assumed that the distances are symmetric. That is, for example: the distance form vertex 1 to vertex 2 is the same as the distance from vertex 2 to vertex 1.

SHEET 4: PROGRAM EXECUTION STEPS

At Sheet 4 the user is informed about the steps he/she has to take in order to successfully execute the algorithm in Sheet 5. These steps can be seen in Figure 62.

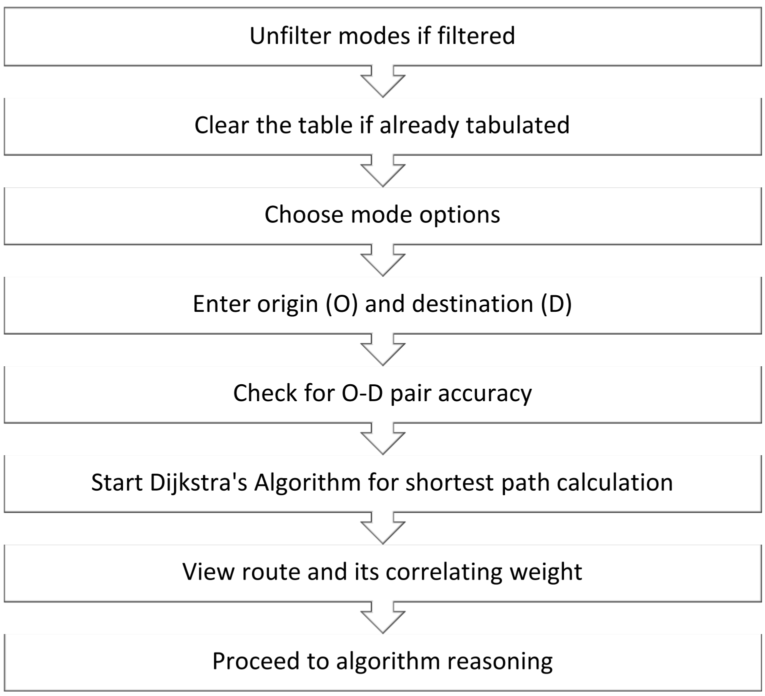

FIGURE 62: MODELLING STEPS

After reading and understanding these steps, the user can choose to either solve Dijkstra SPP based on the shortest distance or the shortest time. A button for each option is available on this sheet.

SHEET 5: DIJKSTRA'S ALGORITHM

At Sheet 5, the user is prompted to enter the data needed for solving the algorithm. Refer to Figure 63.

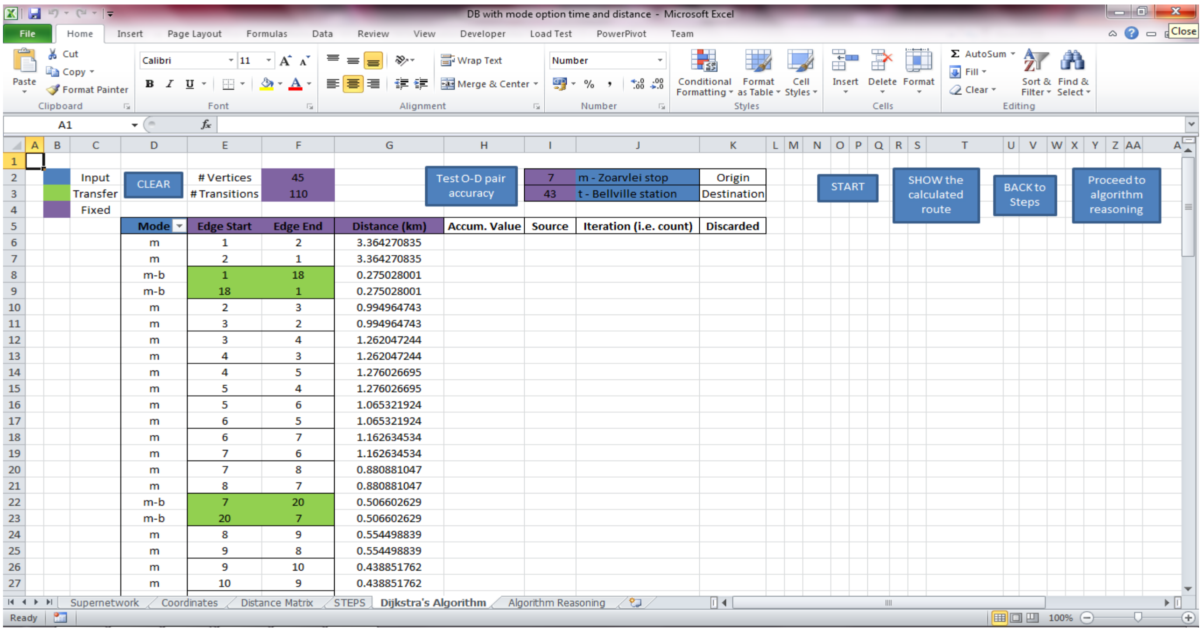

FIGURE 63: THE MAIN INTERFACE OF THE PROGRAM

As can be seen in Figure 64, the blue cells and -buttons are the input required from the user, the green cells represent the transfers, and the purple cells are fixed entries that should not be altered. It is important to note here that, if the user wants to filter the mode options, for example if he/she wants to compute routes solely based on MyCiti (m) and GABS (b), he/she has to choose m, b and m-b, with the m-b option catering for transferring between these two modes. An example of the output (when solved for the shortest distance) can be seen in Figure 64.

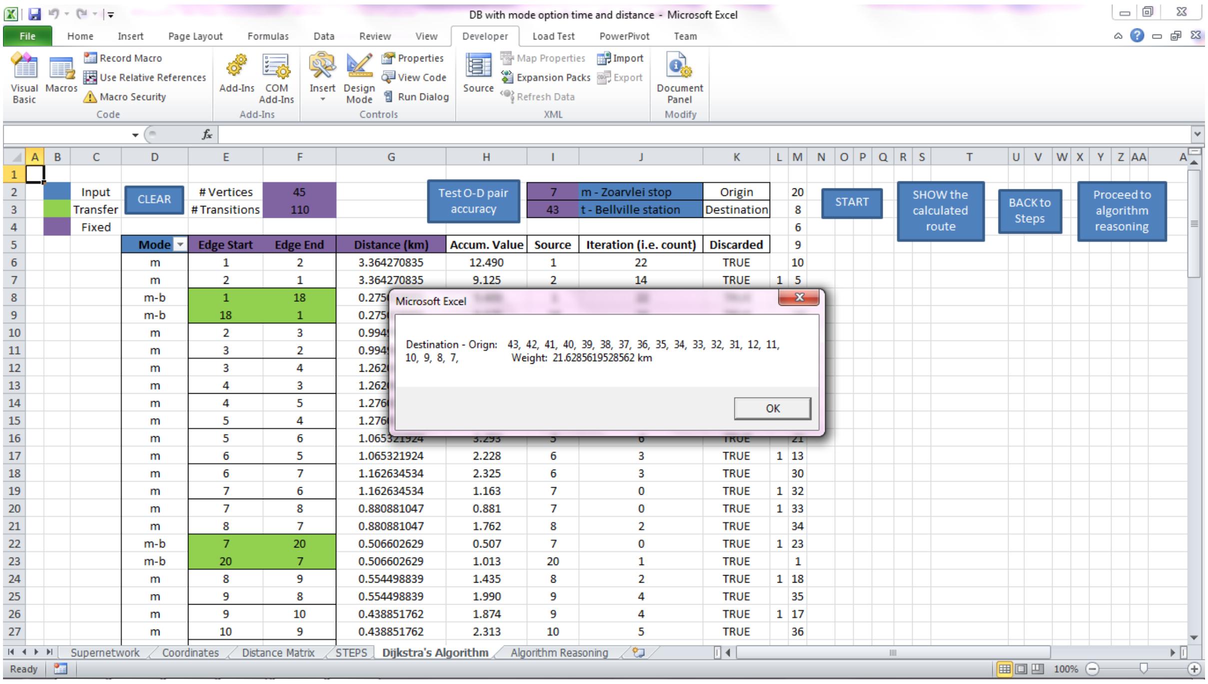

FIGURE 64: AN EXAMPLE OF THE OUTPUT

SHEET 6: ALGORITHM REASONING

The algorithm reasoning is depicted in Figure 65 and follows the ordering shown. That is from step 1 to step 6 and then looping, for the number of vertices, between steps 4 and 6.

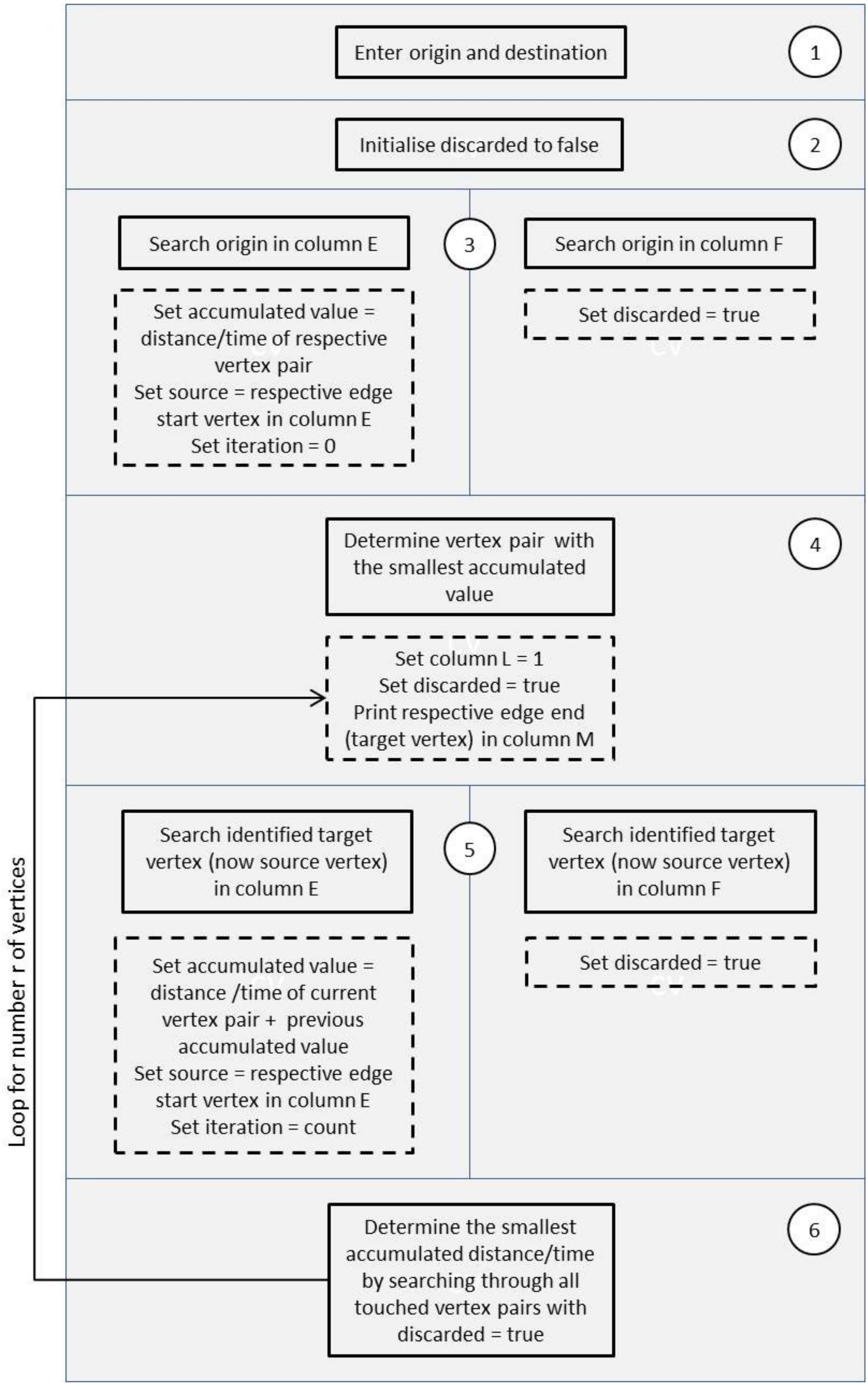

FIGURE 65: ALGORITHM REASONING

5.3.4 LIMITATION TO THE PROGRAM

The following limitations relate to this program:

- The supernetwork used, is fixed. That is, the vertices representing the stops/stations, their respective edges, and the transitions, are fixed.
- The maximum number of vertices is 45 and the maximum number of transitions is 110.
- Ideally one would want the output to be given by stop/station name and mode type, but currently, the output is given in a number format correlating to the numbers given to each stop/station. Furthermore, when a transfer occurs, it is also not distinctly identified.

5.4 DATABASE DEVELOPMENT

The idea proposed herein is to normalise and consolidate the available transport data in order to develop an integrated database that centrally stores the relevant data needed for multimodal routing. Following from this database, the shortest multimodal route options can be portrayed to the transport user through a (web-based) Journey Planner (JP).

5.4.1 THE BACK-END DESIGN

AN INTEGRATED DATABASE

A typical model for an integrated database, required to meet the proposition made herein, is shown in Figure 66. As can be seen in this figure, transport data relating to Metrorail, the private vehicle, MyCiti, and Golden Arrow Bus Services (GABS) are all contained, to a certain degree, at the Transport Information Centre (TIC) in the Transport Management Centre (TMC).

Examples of the data available for the public transport modes are: schedules, fares, passenger counts, and maintenance monitoring. The data available for the private vehicle follows mainly from Freeway Management Systems (FMS). That is, real time traffic monitoring with aid of VMS and CCTV cameras. This data was obtained from Judy Scott of the CoCT and can be viewed in more detail on the attached CD.

(Please note that, as mentioned previously, the Private Vehicle Network (PVN) was not incorporated into the modelling of the multimodal supernetwork and was thus also not included in the development of the database. The inclusion of the private vehicle in Figure 66 was merely for the sake of thoroughness.)

As can be seen in Figure 66, this data can further be categorised based on the type of information stored, its format, and whether it is historic or live (i.e. real time).

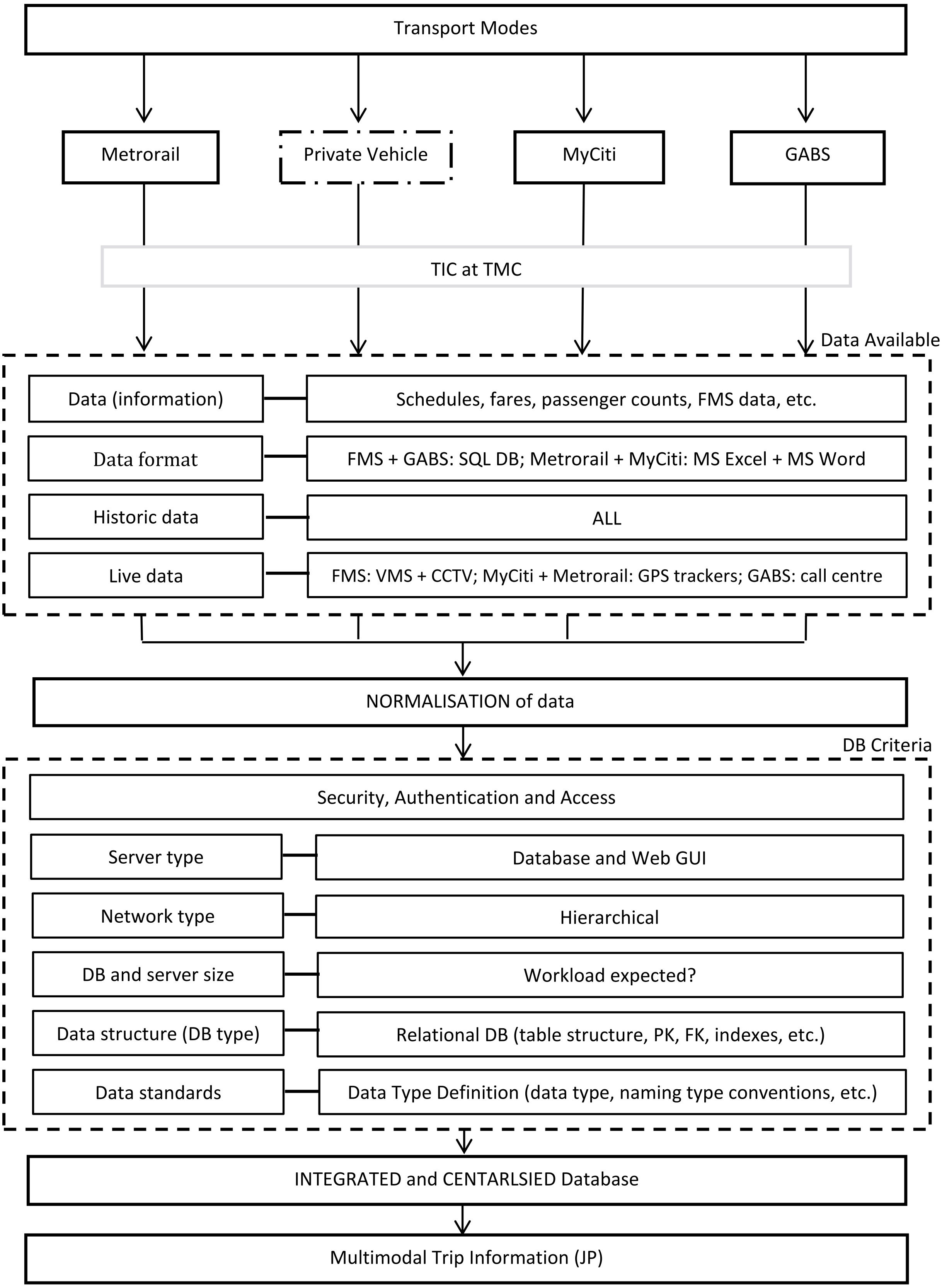

FIGURE 66: A TYPICAL MODEL FOR AN INTEGRATED DATABASE APPROACH

The basic criteria for the design of an integrated database can also be seen in Figure 66. Firstly, the security, authentication and access to the database need to be decided. That is, who has access to the database and what privileges they have (e.g. read, write or read and write). For the purpose of this research project, this was however not considered. Secondly, the appropriate server- and network type need to be decided. For the application of the proposition made herein, it was chosen to use a database and a Web Graphic User Interface (GUI) as the server type with a hierarchical network topology. Thirdly, the database- and server size required, based on the workload expected, need to be determined. Again, for the purpose of this research project, this was not considered. Fourthly, the data structure, according to the database type, need to be determined. And lastly, the data standards, that is, the data type, naming type conventions, and so on, need to be distinguished. Based on the application of the proposition made herein, the development of a relational database was chosen, with the data standards and –structures following from the relational tables developed therein.

5.4.2 THE FRONT-END DESIGN

THE MULTIMODAL INFORMATION SYSTEM

A typical model for a multimodal information system, required to meet the proposition made herein, can be seen in Figure 67. This model is based on a 3-tier client-server architecture in order to accommodate for the provision of a web-based Journey Planner (JP).

As can be concluded from Figure 67, it is proposed to use a Web GUI (Graphic User Interface), e.g. Internet Explorer, as the front-end medium for accessing the relevant data, in a relational database, with an OLAP (Online Transaction Processing) application type, and a hierarchical network as the network topology.

A user who wishes to commute between point 1 and 2 in the given corridor will sign onto the website (i.e. web interface). Here he/she will be prompted to give: the origin, the destination, his/her mode preference and his/her optimisation preference of either time or distance. From here via HTTP (HyperText Transfer Protocol) the information submitted by the user will be send over the network using TCP/IP (Transmission Control Protocol/Internet Protocol) to the application server.

The application server will package the information submitted by the user into the correct format to send it off to the Database Management System (DBMS) over the TCP/IP network. Furthermore, the application server will on a regular (adjustable) interval, via the internet using HTTP, query real time data updates from the various mode operators. This information will then be written back to the DBMS in order to maintain real time accuracy.

The DBMS will return the information the user has requested to the applications server. The application server will again via TCP/IP present the information to the web server. And then lastly, via HTTP over the internet, the requested information will be presented on the web-based JP to be used by the user.

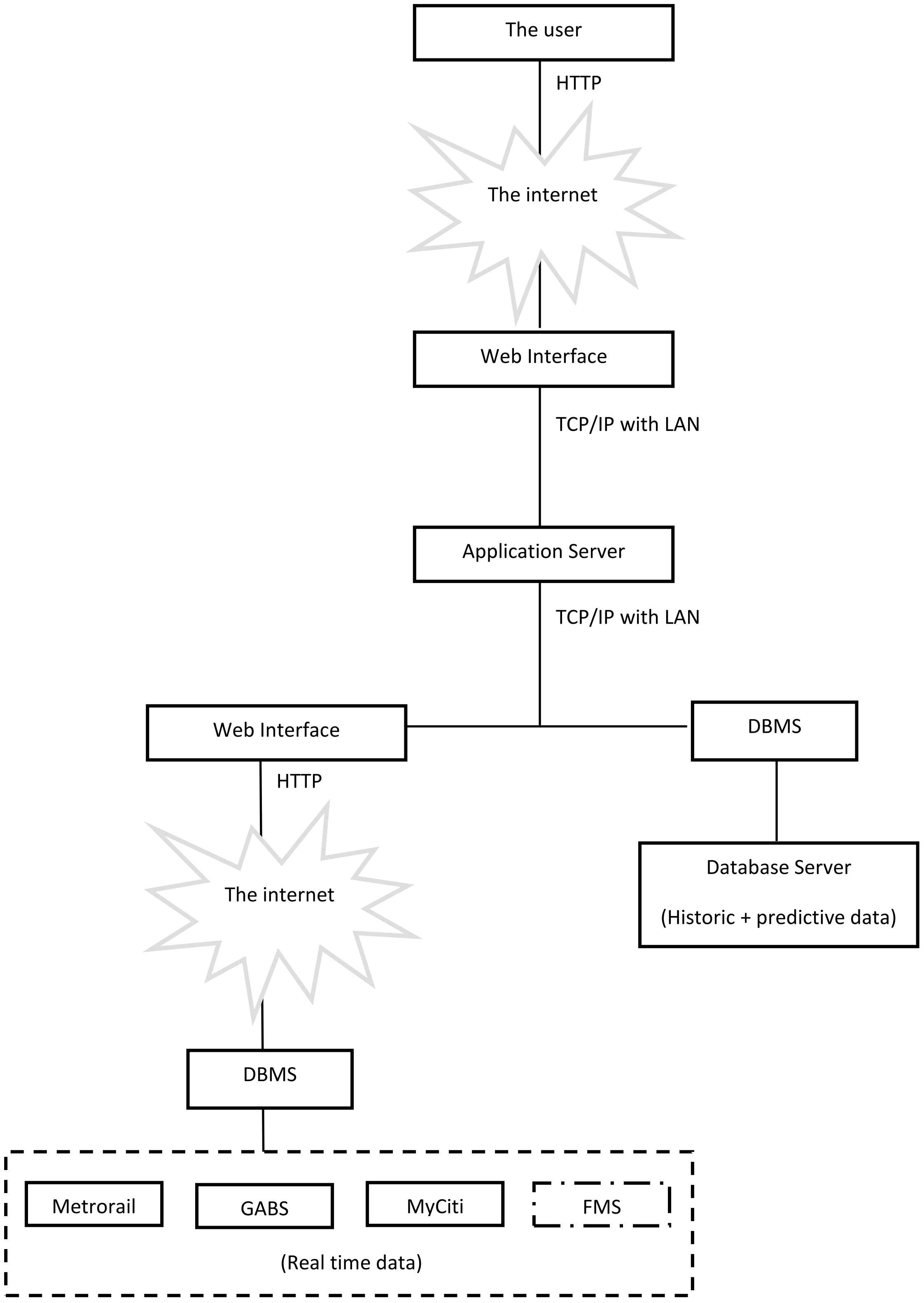

FIGURE 67: A TYPICAL MODEL FOR A MULTIMODAL INFORMATION SYSTEM

(As can be seen in Figure 67, the private vehicle was again, for the sake of thoroughness, shown. It should however be noted that, because real time data is, at this stage, mainly only available for certain freeways, and not for instance for arterials, only the provision of FMS to the multimodal information system suggested, is shown. As mentioned previously, FMS encompass real time traffic monitoring with aid of VMS and CCTV cameras. However, within the near future, when traffic detectors have been implemented, real time travel time data will be available for certain freeway segments. Therefore, with the imminent realisation of this, the incorporation of the PVN, with the proposition made herein, will be more feasible and easily catered for.)

5.4.3 THE ACCESS DATABASE

With the front-end and back-end of the integrated database approach construed, the fine tuning of the database and the design of the multimodal information system relating thereto, can commence.

WHY MICROSOFT ACCESS?

Based on the transport data obtained from Judy Scott of the CoCT, it is fair to assume that Microsoft SQL Server will, in the near future, be dominating as the preferred database type. However, in this research project, Microsoft Access was utilised.

The reasons for programming the database in Microsoft Access (over Microsoft SQL Server) are:

- In comparison to Microsoft SQL Server, the interface of Microsoft Access is more visual and thus makes the programming of a database therein easier and in most cases also faster.
- In Microsoft SQL Server it would have been required to use a programming language in the .Net framework (e.g. C#); in comparison to Microsoft Access in which VBA (Visual Basic for Applications) was required.

Therefore, due to time constraints and due to this author's previous experience and familiarity with VBA, Microsoft Access was chosen. Nevertheless, the same database could have been relatively easily programmed in Microsoft SQL Server.

THE TABLES

A HOLISTIC VIEW OF THE TABLES

In order to provide public transport travellers with a multimodal Journey Planner (JP), it is proposed to utilise the tables represented in Figure 68.

The tables needed to accomplish the proposition made herein were chosen on a reverse engineering basis. That is, because the end product (i.e. the web-based JP) and its relating functions required were known up-front, a backward reasoning process was applied to determine the tables needed in delivering this end product.

In Figure 68, the relationships among the tables are represented in a Venn diagram[26] format.

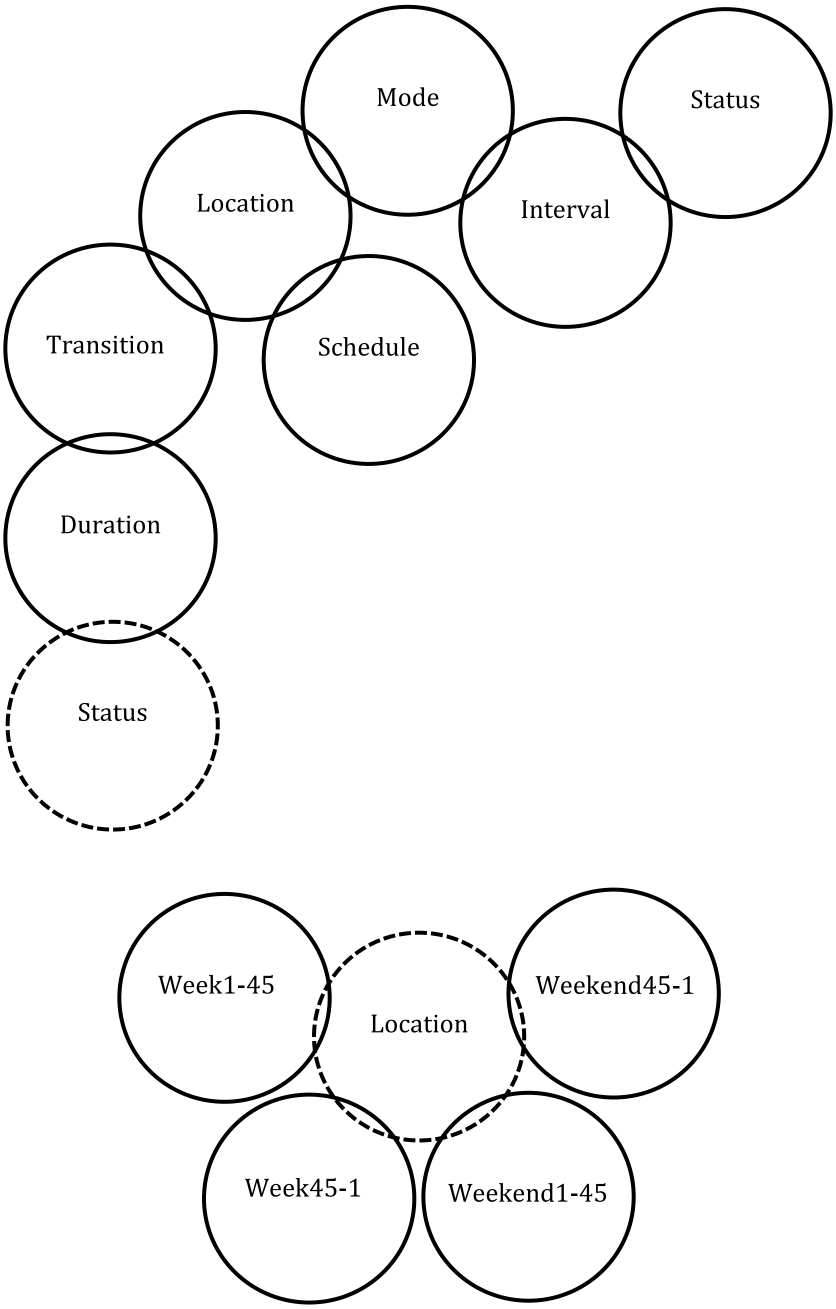

FIGURE 68: A VENN DIAGRAM OF THE TABLES

In Figure 69, a schema diagram for the proposed relational database schema is shown. The primary key and the concatenated keys relating to each relation are underlined. As mentioned

[26] A Venn diagram is a diagram that shows all possible logical relations between a finite collection of sets.

previously, a primary key is an unique identifier for a relation. A concatenated key, however, is used when no unique identifier exists. Thus, a combination of two attributes is used together in order to maintain the uniqueness of the relation.

tblMode

ModeIDLabel	Name

tblStatus

StatusID	Description	FirstStart	FirstEnd	SecondStart	SecondEnd

tblLocation

LocationID	Name	Latitude	Longitude	ModeIDLabel

tblInterval

ModeIDLabel	StatusID	Interval

tblTransition

TransitionID	IDFrom	IDTo	Distance	BackupDistance

tblSchedule

GenID	LocationID	WStartTime	WEndTime	WESTime	WEETime

tblDuration

TransitionID	StatusID	Duration

tblWeek1-45

LocationID	DepartureTime

tblWeek45-1

LocationID	DepartureTime

tblWeekend1-45

LocationID	DepartureTime

tblWeekend45-1

LocationID	DepartureTime

FIGURE 69: A SCHEMA DIAGRAM OF THE TABLES

The tables represented in Figure 69, and their content, were exported from Microsoft Access to Microsoft Excel by using the Microsoft Excel 2010 plug-in program PowerPivot. This exported database can be viewed on the attached CD. (Please note: Microsoft 2010 is required to view the database with PowerPivot.)

A DETAIL VIEW OF THE TABLES

tblMode

Column ModeIDLabel
    Type: Text
    Size: 255
    Description: Mode type (m = MyCiti, b = bus aka GABS and t = train aka Metrorail)
    Primary Key
Column Name
    Type: Text
    Size: 255

tblStatus

Column StatusID
    Type: Text
    Size: 255
    Description: Peak/off-peak
    Primary Key
Column Description
    Type: Text
    Size: 255
Column FirstStart
    Type: Date/Time
    Size: 8
    Description: Start of first off-peak period
Column FirstEnd
    Type: Date/Time
    Size: 8
    Description: End of first off-peak period
Column SecondStart
    Type: Date/Time
    Size: 8
    Description: Start of second off-peak period
Column SecondEnd
    Type: Date/Time
    Size: 8
    Description: End of second off-peak period

ASSUMPTIONS:

In the MyCiti schedule, a clear statement of their peak- and off-peak periods is given. Whereas for Metrorail and GABS, no direct reference to their peak- and off-peak time periods are given. As a result, the peak- and off-peak periods for MyCiti, Metrorail and GABS are deemed the same. It is assumed that the peak morning period is between 06:30 and 09:00. And the peak afternoon period is assumed to be between 15:30 and 19:00. Furthermore, Saturdays, Sundays and public holidays are also considered to be off-peak. Thus, when modelling the modes over the weekend and on public holidays, the data correlating to off-peak (e.g. frequency, start- and end times, etc.) is utilised. This will be considered in more detail under the assumptions of tblSchedule.

tblLocation

Column LocationID
    Type: Text
    Size: 255
    Primary Key
Column Name
    Type: Text
    Size: 255
    Description: Stop/station name
Column Latitude
    Type: Double
    Size: 8
    Description: Measured in radians
Column Longitude
    Type: Double
    Size: 8
    Description: Measured in radians
Column ModeIDLabel
    Type: Text
    Size: 255
    Description: Mode type
    Foreign Key to tblMode

tblInterval

Column ModeIDLabel
    Type: Text
    Size: 255
    Description: Mode type
    Concatenated Key
Column StatusID
    Type: Text
    Size: 255
    Description: Peak/off-peak
    Concatenated Key
Column Interval
    Type: Integer
    Size: 2
    Description: Frequency

ASSUMPTIONS:

The frequency of buses for MyCiti is stated in their schedule. In peak periods, a bus is expected to arrive every 8 minutes, and in off-peak periods, every 20 minutes. The frequency of trains for Metrorail was deducted from their schedule. According to their schedule, it is deemed appropriate to assume a frequency of 15 minutes in peak periods and 45 minutes in off-peak periods. For GABS, a rough approximate was taken. Based on the response of random interviews with a number of bus riders, it is assumed that a bus can be expected every 20 minutes in peak periods and every hour (60 minutes) in off-peak periods.

tblTransition

Column TransitionID
    Type: Long Integer
    Size: 4
    Description: General ID used for uniqueness purposes
    Primary Key
Column IDFrom
    Type: Long Integer
    Size: 4
    Description: From where
    Foreign Key to tblLocation
Column To
    Type: Long Integer
    Size: 4
    Description: To where
    Foreign Key to tblLocation
Column Distance
    Type: Double
    Size: 8
    Description: Great Circle distance in kilometre
Column BackupDistance
    Type: Double
    Size: 8
    Description: Used in conjunction with the real time update and –restore queries

tblSchedule

Column GenID
Type: Long Integer
Size: 4
Description: General ID used for uniqueness purposes
Primary Key
Column LocationID
Type: Long Integer
Size: 4
Foreign Key to tblLocation
Column WStartTime
Type: Date/Time
Size: 8
Description: Start time during the week
Column WEndTime
Type: Date/Time
Size: 8
Description: End time during the week
Column WESTime
Type: Date/Time
Size: 8
Description: Start time during the weekend
Column WEETime
Type: Date/Time
Size: 8
Description: End time during the weekend

ASSUMPTIONS:

From the schedules, it is evident that the start- and end times of each mode are influenced by the day of the week (and by the direction of travel). In MyCiti's schedule, a distinction is made between 1) Monday to Friday and 2) Saturdays, Sundays and Public Holidays. And in the schedules of Metrorail and GABS, a distinction is made between 1) Mondays to Fridays, 2) Saturdays, 3) Sundays and 4) Public Holidays. In order to simplify the implementation thereof, a distinction between only week and weekend is made. For the purpose of this research project, Metrorail's Sunday data was used in modelling their weekend off-peak periods. Therefore, MyCiti's start- and end times correlate to their schedule based on their week- and weekend data; and Metrorail's start- and end times for the week correlate to their week schedule and their Sunday data is used in modelling their weekend off-peak periods. For GABS, random start- and end times for the week and weekend are assumed. Furthermore, as mentioned previously, it was also noted that the modes' start- and end times are influenced by the direction of travel. Therefore, for each mode, the end points in their routes were identified. For MyCiti: Table View and Civic Centre, for GABS: Koeberg Power Station and Durbanville, and for Metrorail: Cape Town station and Brackenfell station. The start- and end times based on departure at each of these end points are tabulated in this table. And the complete schedule, adjusted for the direction of travel, and incorporating week and weekend as well as the frequency of each mode, can be seen in tables, tblWeek and tblWeekend.

tblDuration

```
Column TransitionID
        Type:   Long Integer
        Size:   4
        Concatenated Key
Column StatusID
        Type:   Text
        Size:   255
        Description:    Peak/off-peak
        Concatenated Key
Column Duration
        Type:   Double
        Size:   8
        Description:    Time in minutes
```

ASSUMPTIONS:

It is assumed that the intramodal durations are the same for peak- and off-peak periods. That is, transferring between two points will be the same regardless of the time of the day (or the day of the week). These journey times can be viewed in Figure 57, Figure 58, Figure 59and Figure 60. For MyCiti and Metrorail, it is believed that this assumption is acceptable, since both these modes of transport have allocated roads and railways and are thus, time-wise, not necessarily influenced by the time of the day. GABS on the other hand, will most probably be influenced by the peak- and off-peak periods. However, for the scope of this research project, GABS dependency on time was not taken into consideration.

tblWeek1-45

```
Column LocationID
        Type:   Long Integer
        Size:   4
        Concatenated Key
Column DepartureTime
        Type:   Date/Time
        Size:   8
        Description:    Departure times relating to the direction 1 to 45 during the week
Concatenated Key
```

tblWeek45-1

Column LocationID
Type: Long Integer
Size: 4
Concatenated Key
Column DepartureTime
Type: Date/Time
Size: 8
Description: Departure times relating to the direction 45 to 1 during the week
Concatenated Key

tblWeekend1-45

Column LocationID
Type: Long Integer
Size: 4
Concatenated Key
Column DepartureTime
Type: Date/Time
Size: 8
Description: Departure times relating to the direction 1 to 45 during the weekend
Concatenated Key

tblWeekend45-1

Column LocationID
Type: Long Integer
Size: 4
Concatenated Key
Column DepartureTime
Type: Date/Time
Size: 8
Description: Departure times relating to the direction 45 to 1 during the weekend
Concatenated Key

PLEASE NOTE that, in order to comply with normalisation principles, the data stored in tblWeek and tblWeekend needed to be stored in only two columns. This made the interpretation thereof difficult. As a result, the content of these tables were exported to Microsoft Excel. And by using Microsoft Excel's PivotTable tool, the timetable data could be represented in a more clear and understandable manner. These timetables can be viewed on the attached CD.

THE ENTITY-RELATIONSHIP DIAGRAM

The Entity-Relationship (ER) diagram of the relational database designed can be seen in Figure 70.

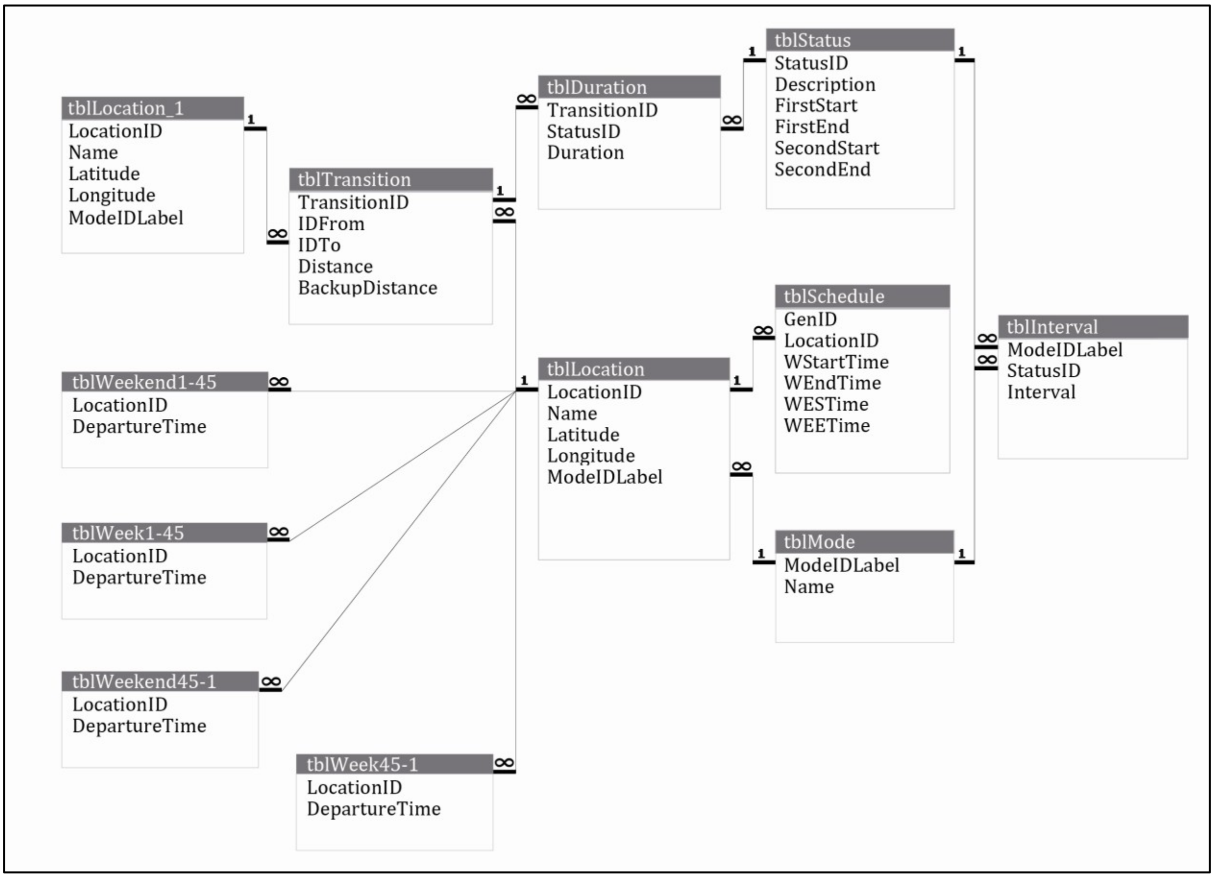

FIGURE 70: THE ER DIAGRAM

THE RELATIONSHIPS

The relationships among the tables in Microsoft Access comply with the following two concepts:

1. Referential integrity is enforced and the updates are cascaded. With these options checked, it ensures that, any time changes to the primary key of a record in a primary table are made, Microsoft Access automatically updates the primary key to the new value in all the related records.
2. A One-To-Many relationship. This means that a row in table A can have many matching rows in table B, but a row in table B can have only one matching row in table A.

A description of the relationships, as depicted in Figure 70, follows.

tblStatus-tblDuration

tblStatus			**tblDuration**
StatusID	1	∞	StatusID

Attributes: Referential integrity enforced, Updates cascaded

Relationship type: One-To-Many

tblTransition-tblDuration

tblTransition **tblDuration**

TransitionID 1 ∞ TransitionID

Attributes: Referential integrity enforced, Updates cascaded

Relationship type: One-To-Many

---

tblMode-tblInterval

tblMode **tblInterval**

ModeIDLabel 1 ∞ ModeIDLabel

Attributes: Referential integrity enforced, Updates cascaded

Relationship type: One-To-Many

---

tblStatus-tblInterval

tblStatus **tblInterval**

StatusID 1 ∞ StatusID

Attributes: Referential integrity enforced, Updates cascaded

Relationship type: One-To-Many

---

tblLocation-tblSchedule

tblLocation **tblSchedule**

LocationID 1 ∞ LocationID

Attributes: Referential integrity enforced, Updates cascaded

Relationship type: One-To-Many

---

tblLocation-tblTransition

tblLocation **tblTransition**

LocationID 1 ∞ IDFrom

LocationID 1 ∞ IDTo

Attributes: Referential integrity enforced, Updates cascaded

Relationship type: One-To-Many

tblLocation-tblWeek1-45

tblLocation **tblWeek1-45**

LocationID 1 ∞ LocationID

Attributes: Referential integrity enforced, Updates cascaded

Relationship type: One-To-Many

---

tblLocation-tblWeek45-1

tblLocation **tblWeek45-1**

LocationID 1 ∞ LocationID

Attributes: Referential integrity enforced, Updates cascaded

Relationship type: One-To-Many

---

tblLocation-tblWeekend1-45

tblLocation **tblWeekend1-45**

LocationID 1 ∞ LocationID

Attributes: Referential integrity enforced, Updates cascaded

Relationship type: One-To-Many

---

tblLocation-tblWeekend45-1

tblLocation **tblWeekend45-1**

LocationID 1 ∞ LocationID

Attributes: Referential integrity enforced, Updates cascaded

Relationship type: One-To-Many

---

tblMode-tblLocation

tblMode **tblLocation**

ModeIDLabel 1 ∞ ModeIDLabel

Attributes: Referential integrity enforced, Updates cascaded

Relationship type: One-To-Many

THE QUERIES

A description of the queries developed in the Microsoft Access database follows.

QRYDIJKSTRAFORW, QRYDIJKSTRAREV AND QRYTIMES

In order to model the difference in departure times based on the direction of travel, qryDijkstraForw and qryDijkstraRev were developed. Refer to Figure 71.

qryDijkstraForw and qryDijkstraRev

IDFrom	ModeIDLabel	IDTo	ModeIDLabel	Distance	Duration

FIGURE 71: QRYDIJKSTRAFORW AND QRYDIJKSTRAREV

As can be seen in Figure 71, both these queries have the same columns. However, for qryDijkstraForw the direction is from vertex 1 to vertex 45 and for qryDijkstraRev the direction is from vertex 45 to vertex 1; thus influencing the IDFrom and IDTo columns of these queries.

In order to model the influence the day of the week has on the departure times, qryTimes was developed. Refer to Figure 72.

qryTimes

LocationID	ModeIDLabel	StatusID	FirstStart	FirstEnd	SecondStart	SecondEnd

WStartTime	WEndTime	WESTime	WEETime

FIGURE 72: QRYTIMES

All three these queries were developed to be used in the modules (discussed in the following Section) in order to tabulate tblWeek1-45, tblWeek45-1, tblWeekend1-45 and tblWeekend45-1.

REALTIMEUPDATE AND RESTOREDISTANCE

In order to incorporate real time data, two update queries were developed: RealTimeUpdate and RestoreDistance. And since the implementation of Dijkstra's algorithm herein can either be solved for time or distance, the weights of each transition's time or distance can thus be updated in order to resemble real time data. However, because the update implementation of either time or distance is very similar, the update queries developed herein only relate to updating a specific transition's distance weight.

If one assumes a scenario in which a bus that runs between two specific consecutive stops is broken, it would be desirable to update this transition's data in order to discard it from forming part of the optimal route.

If the RealTimeUpdate query is selected, the user is first prompted to enter the TransitionID he/she wants to modify. Then after providing this input, the user is prompted to provide the new increased weight (i.e. distance) of the specific transition. This specific transition influenced may be viewed in tblTransition with the new weight seen in its Distance column and the actual weight in its BackupDistance column. It is recommended that the user enters a large value such as 999. Therefore, when Dijkstra's algorithm is executed, this specific transition will be discarded due to its large weight.

Now, if and when a new bus arrives or the initial bus is repaired, it would be desirable to restore the previously affected transition to its official distance. This can be executed by using the RestoreDistance update query. If the RestoreDistance query is selected, the user is prompted to enter the TransitionID he/she wants to be restored. And once this query is executed, the Distance column in tblTransition will again reflect the actual distance (as is stored in the BackupDistance column) correlating to that specific transition.

The action of updating- and restoring the data may seem tedious, but it can in fact be managed by one person for all three the public transport modes considered. Therefore, for the purpose of this research project, these update queries developed are deemed to be sufficient for the incorporation of real time data.

THE MODULES

The modules Week1_45, Week45_1, Weekend1_45 and Weekend45_1 were used in conjunction with qryDijkstraForw, qryDijkstraRev and qryTimes to tabulate tblWeek1-45, tblWeek45-1, tblWeekend1-45 and tblWeekend45-1. The code of these modules can be seen in Section 11.2 The tabulated tables relating to each of these modules can be viewed on the attached CD by using the Microsoft Excel 2010 plug-in program PowerPivot.

THE FORM

The ultimate idea is to provide the public transport user with a web-based multimodal Journey Planner (JP) from where he/she can query the database to determine the shortest (time or distance) path based on his/her personal criteria; i.e. origin, destination, mode preference, optimisation preference, and preferred arrival time.

The actual front-end Graphic User Interface (GUI) was not developed. However, as an example of a possible GUI, the JP in Figure 73 was compiled in Microsoft Access.

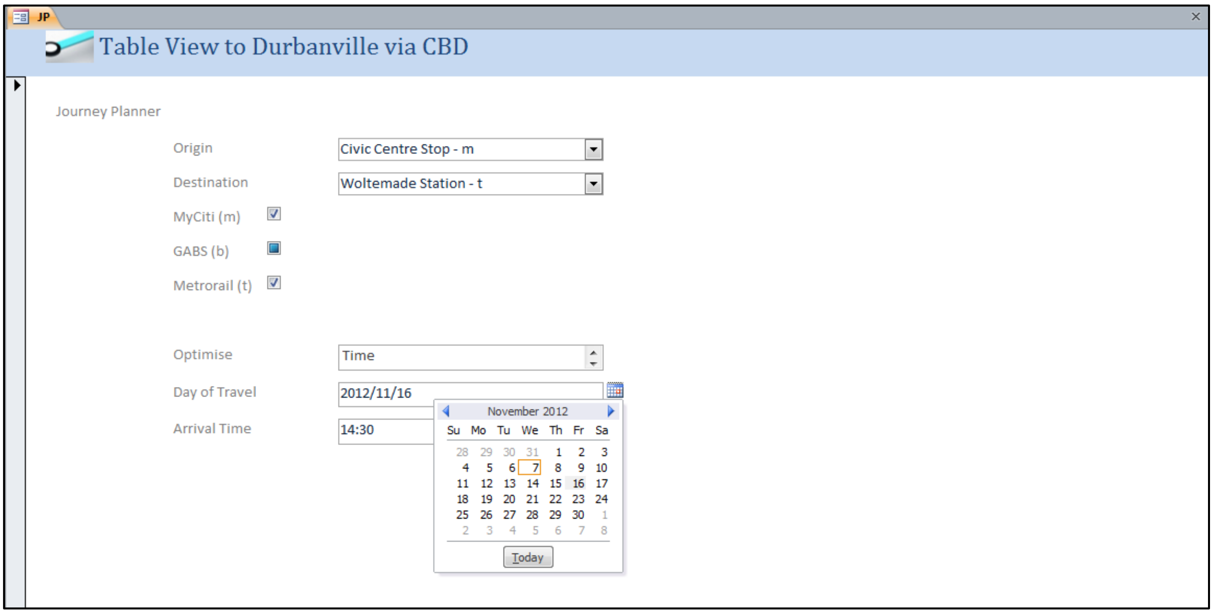

FIGURE 73: THE JOURNEY PLANNER GUI

It should be emphasised that the appropriate connections between the JP and the database have not been implemented. In essence it would be desirable to provide the public transport users with such an interface (most likely through the web) and to execute Djkstra's Algorithm by using the data stored in the centralised (Microsoft Access) database.

6. RESULTS

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6.1 THE GENERIC FRAMEWORK USED IN DEVELOPING A MULTIMODAL PLATFORM

A summary of the implementation steps used, in obtaining a multimodal platform, can be seen in Table 14.

TABLE 14: THE GENERIC FRAMEWORK USED IN DEVELOPING A MULTIMODAL PLATFORM

STEPS	ASPECTS	CONSIDERATIONS	FOUNDATION	USED
1	Mode Selection	MyCiti, Metrorail, GABS, privately owned vehicles, (minibus taxis, metered-taxis)		MyCiti, Metrorail, GABS
2	The Multimodal Transport Network Design	Supernetwork, Hierarchical Network	Graph Theory	Supernetwork
3	Modelling User Constraints	Deterministic Finite State Automaton, Nondeterministic Finite State Automaton	Finite State Automata, Language Theory	N/A
4	The Networks	Private Vehicle Network, Public Transport Network, Foot (Pedestrian) Network		Public Transport Network
5	The Graph Models	The Condensed Model, The Time Expanded Model, The Time Dependent Model	Time Independent, Time Dependent	Time Independent
6	Vertex- and Edge Type	Physical-, Event-, Transfer- and Route vertices; Physical-, Transfer- and Trip sequence Edges		N/A
7	Weight Metric for Optimisation	Travel Time, Geographical Distance (Euclidean Method, Great Circle Method), Generalised-Cost approach		Travel Time (Independent of the time of the day and the day of the week), Geographical Distance (The Great Circle Method)

STEPS	ASPECTS	CONSIDERATIONS	FOUNDATION	USED
8	Merge- and Link Operations	Linear Search, K-D trees	Nearest Neighbour Problem	N/A
9	Routing Algorithm	Shortest Path Problem (SPP), Many-to-Many SPP, One-to-All SPP, All-pairs SPP	Earliest Arrival Problem, Dijkstra's Regular Language Constrained SPP	Dijkstra's SPP
10	Network Size	Bi-directional Search, Goal-directed Search, Pre-processing Contraction Hierarchies	Speed-up Techniques	N/A
11	Advanced Traffic Management Systems	Freeway Management Systems, Arterial Management Systems, Urban Traffic Control	Intelligent Transport Systems (ITS)	VMS, CCTV cameras (incorporated in corridor selection)
12	Advanced Public Transport Systems	Automated Vehicle Location, Electronic Fare Payment (Automated Fare Collection and Interoperable Fare Management), Advanced Traveller Information Systems	Intelligent Transport Systems	EFP: IFM structure, ATIS: Journey Planner (JP)
13	Data Repository Type	Database, Data Warehouse		Database
14	The Database Management System	Online Transaction Processing, Operational Data Store, Online Analytical Processing, Data Warehouse/Data Mart		OLTP: Online Transaction Processing
15	Sharing the Database	Security, Authentication and Access to the Database	The Database Management System	N/A
16	Data Models	High-level, Low-level, Representational (i.e. Legacy and Relational)		Relational Data Model
17	Defining the Relational Database	Domains, Attributes, Tuples, Relations, Relation Schemas, Relational Database Schema and –State		Relational Database Schema Diagram

STEPS	ASPECTS	CONSIDERATIONS	FOUNDATION	USED
18	Managing the Relational Database	Relational Database Schema Constraints: Domain constraints, constraints on NULL values, Primary key constraints and Integrity constraints (i.e. Entity and Referential)	Relational Database Management	Referential Integrity enforced, Updates cascaded, Relationship type: One-To-Many
19	Database Type	Microsoft SQL Server, Microsoft Access, Oracle		Microsoft Access
20	Data Standards	Data Type, Data Structure, Naming Conventions	Normalisation Principles	(Follows from the relational tables developed in MS Access)
21	Server Type	Database, Web Graphic User Interface (GUI)	User Interface	Database, Web GUI
22	Server Architecture	2-Tier Client-Server, 3-Tier Client Server		3-Tier Client Server Architecture
23	Network Type	Hierarchical, Star, Ring, Bus	Network Topologies	Hierarchical Network Type
24	The Value of Information	The Information Quality Attributes, The Information Valuator, The Information Service Value Chain	Information Theory, Value Theory, Utility Theory	N/A
25	Passenger Travel Information Needs	Pre-trip, on-trip, end-trip phase		Pre-trip phase
26	Information Services deemed Important by the Travellers	JP criteria: 1) transport modes covered 2) sufficiency of static journey information provided 3) geographical coverage 4) quality of information display 5) sufficiency of itineraries offered 6) real time information capability 7) sufficiency of on-trip information provision 8) ticket booking capability 9) the means for information service accessibility	The Value of Information	(Adjustment for real time data was made)
27	Travellers' Choice Behaviour on Information Service Media	Personal Attributes, Information Attributes, Usage of Internet and Mobile Phone		N/A
28	The provision of personalised Information	Automated Fare Collection, RFID	Personalised ITS	Model for IFM structure

STEPS	ASPECTS	CONSIDERATIONS	FOUNDATION	USED
29	A Multimodal Framework Architecture	Overall Conceptual Aspects, Logical Aspects, Conceptual Aspects		Benchmark ARKTRANS: MultiRIT

As can be seen in Table 14, a number of the implementation steps were marked as N/A. The reasoning behind this will be discussed per implementation step per each main focus area.

Multimodal Transport

Implementation steps 3 and 6:

Since the goal of this research project is to both create awareness of the benefits, and to develop an implementation framework for the attainment, of a multimodal platform, the implementation of these two steps was omitted. However, step 3 (i.e. the modelling of the user constraints) was, to a certain extent, incorporated in the Microsoft Excel program developed herein. That is, the user is given the option to model his/her mode preferences.

Implementation steps 8 and 10:

Due to the size of the supernetwork, resulting from the corridor selected herein, being relatively small, neither of these two steps was required.

Database Development

Implementation step 15:

Again, based on the goal of this research project, the incorporation of this step (i.e. the sharing of the database) was not required. That is, the database developed in Microsoft Access is merely seen as a pilot implementation of how the proposed centralised database, required for multimodal applications, would possibly work.

Journey Planner

Implementation steps 24 and 27:

Again, based on the goal of this research project, the requirements of a front-end Graphic User Interface (GUI) was researched, but the actual GUI, with the appropriate connections to the database, was not developed. The Microsoft Excel program developed herein is created separately from the database. Therefore, with this program, the user is only provided with pre-trip information. And as a result, the incorporation of these two steps was not needed.

6.2 THE CURRENT PRACTICE FOLLOWED VERSUS THE PROPOSED SOLUTION

The implications of implementing a multimodal transport system are shown in Table 15. This table compares this research project's proposed solution to the current practice followed. The corresponding advantages and disadvantages of each, as listed therein, became clear with the completion of this research project.

TABLE 15: CURRENT PRACTICE FOLLOWED VERSUS PROPOSED SOLUTION

THE CURRENT PRACTICE FOLLOWED		**THE PROPOSED SOLUTION**
Multiple unimodal transport networks	**1**	A single integrated transport network
Separate fare media with separate fare structures	**2**	Integrated schedules and -fares
Uncoordinated transport services	**3**	Synchronised and coordinated transport services
Multiple unimodal Journey Planners (JPs)	**4**	A single multimodal JP accessed from one portal
Travellers experiencing cognitive overload by having to integrate different information service media	**5**	Informed (i.e. intelligent) travellers that are provided with personalised information on their chosen route(s)
Transport payments that require cash transactions	**6**	Simplified payment options with aid of electronic ticketing
The endure of the private vehicle trend	**7**	An improve in public transport's image
Transport data housed in many separate subsystems	**8**	Transport data integrated and housed in a centralised database
No form of institution integration	**9**	Reduction in system costs through public-private partnerships
Travellers caught up in events such as incidents and delays	**10**	Reduction in overall system travel times and delays

6.3 THE RECOMMENDED WAY FORWARD

This author recommends that the City of Cape Town (CoCT) continues to enforce its transport networks with ITS initiatives, with specific focus placed on the improvement of its current Advanced Public Transport Systems (APTS). This will then provide the City with the necessary leverage to develop a centralised database, from where the realisation of a multimodal JP can be spurred on. Then, if the City utilises the generic (sequential) framework developed herein, the attainment of multimodal transport, and the implementation thereof, can be conducted in a more controllable manner. Moreover, the City can then be used to test the feasibility, acceptance and socio-economical impact of the proposition made herein. If the then found implications of the implemented multimodal platform, portray the expected implications (as seen in Table 15), expansion is recommended. Ideally, a multimodal transport system can be implemented nation-wide and the opportunities and subsequent riches arising therefrom can allow South Africa to be at par with other countries in the world.

7. CONCLUSIONS

In this research project the steps required in achieving a multimodal platform, within the context of the CoCT's (City of Cape Town's) land transport networks, were researched. It is believed that, if a multimodal transport system is promoted, the deficiencies of the current heterogeneous non-integrated systems may be overcome. This research project thus stipulates the sequential approach needed in achieving an integrated (sustainable) public transport system. The goal of this research project is to create awareness of the benefits that may arise from, and the implementation steps required in achieving, such a multimodal platform. After conducting research in this field, the following portraying aspects were found.

The foremost important aspect found is the evident enormity and complexity of the proposition made herein. The main focus areas for implementing a multimodal platform, as identified herein, are: 1) the multimodal transport network and the design and modelling thereof, 2) the role of Intelligent Transport Systems (ITS) in achieving a multimodal platform, 3) the need for and the design criteria of a (centralised) database, and 4) the need for and the travel information requirements of a multimodal Journey Planner (JP). These focus areas each originates from different disciplines, with each encompassing different aspects, based on unique considerations and foundations.

Secondly, the generic (sequential) framework for achieving a multimodal platform, as developed herein, gives 1) perspective on the extensity, and 2) provides for a simplistic and thus more controllable implementation, of the research proposition. Furthermore, with the successful completion of this research project, the logical application of this generic framework, as tested herein, is deemed appropriate for the implementation, and also necessary to address the complexity, of multimodal transport.

Thirdly, it was found that, for a developing country like South Africa, the economic- and social health of the nation (with respect to its transport networks), depend to a large extent, on the development of an efficient Advanced Traveller Information System (ATIS). Moreover, with travellers' evident inclination to acquire more information, the realisation of a multimodal Journey Planner (JP) is found to be cardinal to the acceptance of a multimodal transport system. As a result, the role that technology plays, and thus the need to reinforce the transport networks with ITS applications, is unmistakeable. Fortunately, with the evolvement of information technology, immense scope for growth in the utilisation of information systems, within the transport industry, has been created. And as a result, new integrated approaches needed in attaining multimodal transport, that are available on various information service media, accessible from anywhere, and that provide travellers with the appropriate personalised information, can, accordingly, be spurred on.

Fourthly, with the successful completion of this research project, the feasibility and ease of implementing a centralised database as well as a multimodal JP (needed for the realisation of multimodal transport) are apparent. Both the database and the JP developed herein contain historic data. However, in the database, the incorporation of real time information was catered for with aid of update queries. Nonetheless, their resulting benefits and scope for application are still clear. Furthermore, only the Public Transport Network (PTN) was incorporated into the modelling of the multimodal supernetwork and was thus also not included in the development of the database. Nevertheless, with the imminent implementation of traffic detectors, and thus real time travel time data being available for certain freeway segments, the incorporation of the Private Vehicle Network (PVN), as well as the provision of real time information, will be more easily catered for.

In conclusion this author submits that, even though the concept of multimodal transport is in its infancy, the need for a multimodal platform and the believed positive outcomes that await those that embark on this path, are evident. Furthermore, with the generic step-wise approach in achieving such a platform stipulated herein, an integrated sustainable transport system, possibly nation-wide, can be spurred on. Once again, South Africa offers the entrepreneur many opportunities and subsequent riches as they are identified and developed.

8. RECOMMENDATIONS FOR FUTURE RESEARCH

The following main recommendations can be made for future research and development. These are discussed in Table 16.

TABLE 16: RECOMMENDATIONS

The Supernetwork	The Algorithm	The Database	The Journey Planner
If the size of the supernetwork grows, then: 1) use the Nearest Neighbour method in linking and merging the individual unimodal networks and 2) use the appropriate speed-up techniques.	Incorporate the PVN (Private Vehicle Network), a foot (pedestrian) network and the minibus taxis into the model proposed herein.	Cater for better real time data by using VMS (Variable Message Signs), CCTV (Closed Circuit Television) cameras, and GPS tracking devices installed in buses, trains and vehicles.	Additional input to the JP (Journey Planner): 1) the option of stating the maximum preferable transfer length as well as the maximum preferable number of transfers, 2) using a generalised cost approach in calculating the optimum route, at differential importance, given by the traveller concerned in making the choices and 3) the incorporation of cost (i.e. fares) with the users' optimisation preference criteria.
	Improve the algorithm used herein to that of DRegLC SPP by using NFA (Nondeterministic Finite Automata) and language theory.	Adapt the current database to Microsoft SQL Server since, according to the transport data obtained from the CoCT, it is fair to assume that Microsoft SQL Server will, in the near future, be dominating as the preferred database type.	Additional output given by the JP: 1) information about fare costs with the help of initiatives such as AFC (Automated Fare Collection) and IFM (Interoperable Fare Management), 2) the offering of door-to-door information logic, that is, directions to and from the respective stops/stations and 3) the provision of on-trip on end-trip information.

The Supernetwork	The Algorithm	The Database	The Journey Planner
	Incorporate time-dependency in the PTN (Public Transport Network); that is, modelling it as a realistic time dependent graph with constant transfer times.	Incorporate time- and profile queries.	Finalise the connections needed between the web interface, the application server and the DBMS (Database Management System) in order to make the JP application accessible through the internet and thus also on mobile smart phones.
Conduct a financial analysis and an economic assessment on the proposition made herein.			

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11. APPENDICES

11.1 Dijkstra's Algorithm: Microsoft Excel VBA Code 199
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11.1 DIJKSTRA'S ALGORITHM: MICROSOFT EXCEL VBA CODE

An example of Dijkstra's Algorithm, programmed in VBA (in Spanish), was found at: http://www.pcreview.co.uk/forums/dijkstra-algorithm-excel-t2834169.html. This example was analysed and adjusted to suit the specific requirements of this research project. The adjusted version thereof follows.

```
Sub Clear()
Range("D1").Select  'Clear count
Selection.ClearContents
Columns("M:M").Select
Selection.ClearContents 'Clear contents of M:M
Dim transitions As Range
Set transitions = Range("E5", Range("E5").End(xlDown)).SpecialCells(xlCellTypeVisible)
Dim rRow As Range
For Each rRow In transitions.Rows 'Iterate for visible rows
Cells(rRow.Row, 8).Select   'Select visible cells in column H
  If IsNumeric(ActiveCell) Then
    Cells(rRow.Row, 8).Select 'Column H
    Selection.ClearContents
    Cells(rRow.Row, 9).Select 'Column I
    Selection.ClearContents
    Cells(rRow.Row, 10).Select 'Column J
    Selection.ClearContents
    Cells(rRow.Row, 12).Select 'Column L
    Selection.ClearContents
```

```
    End If
Cells(rRow.Row, 11).Select   'Select visible cells in column K
    If IsNull(ActiveCell) = False Then
        Cells(rRow.Row, 11).Select 'Column K
        Selection.ClearContents
     End If
Next rRow
Range("K5") = "Discarded"
Cells(1, 1).Select
End Sub

Sub Test()  'Test O-D pair accuracy
Dim transition_count As Integer    'Count visible rows after being filtered
transition_count = Range("D6:D115").SpecialCells(xlCellTypeVisible).count
Cells(3, 6) = transition_count 'Number of transitions: F3
Dim NN As Integer   'Number of vertices
If transition_count = 24 Then   'Only MyCiti
    NN = 13
    If Cells(2, 9).value > 13 Or Cells(3, 9).value > 13 Then
        MsgBox ("Error: Origin/destination should be smaller than or equal to 13")
    Else
        MsgBox ("O-D pair is accurate")
    End If
End If
If transition_count = 64 Then   'MyCiti and GABS
    NN = 29
    If Cells(2, 9).value > 29 Or Cells(3, 9).value > 29 Then
        MsgBox ("Error: Origin/destination should be smaller than or equal to 29")
    Else
        MsgBox ("O-D pair is accurate")
    End If
End If
```

```
If transition_count = 58 Then   'MyCiti and Metrorail
  NN = 29
  If (Cells(2, 9).value > 13 And Cells(2, 9).value < 30) Or (Cells(3, 9).value > 13 And Cells(3, 9).value < 30)
Then
    MsgBox ("Error: Origin/destination should be smaller than or equal to 13 or greater than or equal to
30")
  Else
    MsgBox ("O-D pair is accurate")
  End If
End If
If transition_count = 32 Then   'Only GABS
  NN = 16
  If Cells(2, 9) < 14 Or Cells(2, 9) > 29 Or Cells(3, 9) < 14 Or Cells(3, 9) > 29 Then
    MsgBox ("Error: Origin/destination should be greater than 13 and smaller than or equal to 29")
  Else
   MsgBox ("O-D pair is accurate")
  End If
End If
If transition_count = 74 Then   'GABS and Metrorail
  NN = 32
  If Cells(2, 9).value < 14 Or Cells(3, 9).value < 14 Then
    MsgBox ("Error: Origin/destination should be greater than 13 and smaller than or equal to 45")
  Else
    MsgBox ("O-D pair is accurate")
  End If
End If
If transition_count = 30 Then   'Only Metrorail
  NN = 16
  If Cells(2, 9).value < 30 Or Cells(3, 9).value < 30 Then
    MsgBox ("Error: Origin/destination should be greater than or equal to 30 and smaller than or equal
to 45")
  Else
    MsgBox ("O-D pair is accurate")
```

```
    End If
End If
If transition_count = 110 Then   'ALL: MyCiti, GABS and Metrorail
    NN = 45
    If Cells(2, 9).value > 45 Or Cells(3, 9).value > 45 Then
        MsgBox ("Error: Origin/destination should be smaller than or equal to 45")
    Else
        MsgBox ("O-D pair is accurate")
    End If
End If
Cells(2, 6) = NN 'Number of vertices: F2
End Sub

Sub Dijkstra_SPP()  'Dijkstra_SPP Sub Procedure
Dim origin As Integer
origin = Range("I2").value  'Set origin as I2
Dim destination As Integer
destination = Range("I3").value 'Set destination as I3
Columns("M:M").Select
Selection.ClearContents 'Clear contents of M:M
Dim transitions As Range
Set transitions = Range("E5", Range("E5").End(xlDown)).SpecialCells(xlCellTypeVisible)
Dim rRow As Range
For Each rRow In transitions.Rows 'Iterate for visible rows
Cells(rRow.Row, 11).Select   'Select visible cells in column K
ActiveCell.FormulaR1C1 = "=FALSE"   'Iniltialise entry in column K with False
Cells(rRow.Row, 8).Select   'Select visible cells in column H
    If IsNumeric(ActiveCell) Then
        Cells(rRow.Row, 8).Select 'Column H
        Selection.ClearContents
        Cells(rRow.Row, 9).Select 'Column I
        Selection.ClearContents
```

```
        Cells(rRow.Row, 10).Select 'Column J
        Selection.ClearContents
        Cells(rRow.Row, 12).Select 'Column L
        Selection.ClearContents
    End If
Range("K5") = "Discarded"
Next rRow
For Each rRow In transitions.Rows
    Cells(rRow.Row, 5).Select   'Select visible cells in column E
    If IsNumeric(ActiveCell) Then
    Dim value As Integer
    value = ActiveCell.value 'Set value equal to current entry in the edge start column
        If (value = origin) Then    'If the entry in the edge start column equals the origin...
            ActiveCell.Offset(0, 3).value = ActiveCell.Offset(0, 2).value   'Set accumulated value to distance
            ActiveCell.Offset(0, 4).value = origin  'Set source equal to the origen
            ActiveCell.Offset(0, 5).value = 0   'Set iterattion equal to 0
        End If
        If (ActiveCell.Offset(0, 1).value = origin) Then 'If the entry in the edge end column equals the origin...
            ActiveCell.Offset(0, 6).value = True 'Set discarded equal to True
        End If
    End If
Next rRow
Dim variables() As Integer
ReDim variables(45) 'ARRAY: maximum number of vertices
Dim i As Integer
For i = 0 To 45
    variables(i) = 0    'ARRAY: Set all variables equal to 0
Next i
variables(origin) = 1   'ARRAY: Set the variable that is equal to the origin to 1
Dim already As Boolean  'Can only be True or False
already = False 'Initialise already to False
Dim count As Integer    'Number of iterations
```

```
count = 1
While (already = False) 'Iterate for already equal to False
   Dim num As Integer
   num = Dijkstra(count)  'Refer to the Dijkstra Function Procedure
   variables(num) = 1  'If the varaible i equals num, set it equal to 1
   count = count + 1
   Dim j As Integer
   Dim counting As Integer
   counting = 0
   For j = 0 To 45   'Iterate for maximum number of vertices
      counting = counting + variables(j)
   Next j
   If (counting >= Cells(2, 6).value) Then   'All the entries have been visited
      already = True
   End If
   Cells(count, 13) = num  'Column M
Wend    'End while loop when condition is not met
Cells(1, 1).Select
End Sub

Function Dijkstra(counts As Integer)   'Dijkstra Function Procedure
Dim valueless As Double
valueless = 9999    'Random (large) initial value
Dim position As Integer
position = 0
Dim transitions As Range
Set transitions = Range("E5", Range("E5").End(xlDown)).SpecialCells(xlCellTypeVisible)
Dim rRow As Range
For Each rRow In transitions.Rows
   Cells(rRow.Row, 8).Select   'Select visible cells in column H
   If IsNumeric(ActiveCell) Then
      Dim valuee As Double
```

```
    valuee = ActiveCell.value 'Set valuee equal to current entry in the accumulated column

    Dim response As Boolean

     response = IsEmpty(ActiveCell)  'Set response of the active cell equal to True (variable is
     uninitialised) or False (otherwise)

     If (response = False And valuee < valueless And ActiveCell.Offset(0, 3).value = False) Then '...And
     current enrty in dicarded column = False

        valueless = valuee  'Valueless obtains the smallest accumulated value

        position = rRow.Row 'Row position of the smallest accumulated value

    End If

  End If

Next rRow

Dim resp As Boolean 'Can only be True or False

resp = True

Dim Number As Integer

Number = Cells(position, 6) 'Set number equal equal to the entry in the edge end column that correlates
to the position of the smallest accumulated value

Cells(position, 12) = 1 'Set the cell in column L that correlate to the position of the smallest accumulated
value equal to 1

Call Terminate(Number, valueless, counts)   'Refer to Terminate Sub Procedure

Dijkstra = Number

End Function


Sub Terminate(x As Integer, y As Double, z As Integer)  'Terminate Sub Procedure: x = number, y =
valueless, z = counts

Dim transitions As Range

Set transitions = Range("E5", Range("E5").End(xlDown)).SpecialCells(xlCellTypeVisible)

Dim rRow As Range

For Each rRow In transitions.Rows

  Cells(rRow.Row, 5).Select   'Select visible cells in column E

  If IsNumeric(ActiveCell) Then

    Dim value As Integer

    value = ActiveCell.value   'Set value equal to entry in the edge start column

    If (value = x) Then 'If the current entry in the edge start column equals number

       If (IsEmpty(ActiveCell.Offset(0, 3)) Or ActiveCell.Offset(0, 3).value > (ActiveCell.Offset(0, 2).value +
      y)) Then   '...Or if accumulated value > distance + valueless
```

```
          ActiveCell.Offset(0, 3).value = ActiveCell.Offset(0, 2).value + y   'Accumulated value = distance + valueless

          ActiveCell.Offset(0, 4).value = x   'Source = number

          ActiveCell.Offset(0, 5).value = z   'Iteration = counts

        End If

      End If

      If (ActiveCell.Offset(0, 1).value = x) Then 'If the entry in the edge end column equals number...

        ActiveCell.Offset(0, 6).value = True    'Discarded = True

      End If

    End If

Next rRow

End Sub


Sub Route1()    'Route1 Sub Procedure

Dim origin As Integer

origin = Range("I2")

Dim destination As Integer

destination = Range("I3")

If Cells(5, 7).Text = "Duration (min)" Then  'Determine whether time or distance and refer to Route Function Procedure

  MsgBox ("Destination - Orign:   " + Str(destination) + ", " + Route(destination, origin, 1) + " min")

Else

  MsgBox ("Destination - Orign:   " + Str(destination) + ", " + Route(destination, origin, 1) + " km")

End If

End Sub


Function Route(number1 As Integer, origin As Integer, Optional yes As Integer)  'Route Function Procedure

Dim dist As String

dist = " "  'Initailise dist to empty string

If (number1 = origin) Then  'number1 = destination...vertices...origin

  Route = " "

Else
```

```
    Dim prevnum As Integer
    Dim response As String
    Dim transitions As Range
    Set transitions = Range("E5", Range("E5").End(xlDown)).SpecialCells(xlCellTypeVisible)
    Dim rRow As Range
    For Each rRow In transitions.Rows
        Cells(rRow.Row, 6).Select   'Select visible cells in column F
        If IsNumeric(ActiveCell) Then
            Dim value As Integer
            value = ActiveCell.value   'Set value equal to the entry in the edge end column
            If (value = number1 And ActiveCell.Offset(0, 6).value = 1) Then '...And column L equals 1
                prevnum = ActiveCell.Offset(0, -1).value    'Set prevnum equal to the edge start column
                If (yes = 1) Then   'Only used for Route and Distance Sub Procedure (thus number1=destination)
                    dist = " Weight: " + Str(ActiveCell.Offset(0, 2).value)   'Set dist equal to value in accum. column
                End If
                response = Str(ActiveCell.Offset(0, -1).value)  'Set response equal to the entry in edge start
            End If
        End If
    Next rRow
        Route = response + ", " + Route(prevnum, origin) + dist 'Iterate within Route Function Procedure
End If
Cells(1, 1).Select
End Function
```

11.2 ACCESS DATABASE

11.2.1 MODULE WEEK1_45

```
Public Sub Week1_45()

Dim gryTimes As Recordset

Set qryTimes = CurrentDb.OpenRecordset("qryTimes")

Dim qryDijkstra As Recordset

Set qryDijkstra = CurrentDb.OpenRecordset("qryDijkstraForw")

Dim tblInterval As Recordset

Set tblInterval = CurrentDb.OpenRecordset("tblInterval")

Dim tblWeek1_45 As Recordset

Set tblWeek1_45 = CurrentDb.OpenRecordset("tblWeek1-45")

Dim Interval_P As Date

Dim Interval_O As Date

Dim Origin As Integer

Dim Destination As Integer

Dim Duration As Date

Dim StartTime As Date

Dim EndTime As Date

Dim IntervalTime As Date

Do Until qryTimes.EOF

  If qryTimes!ModeIDLabel = "m" Then    'Table population then the mode is "m"

    StartTime = CDate(qryTimes!WStartTime)

    IntervalTime = CDate(qryTimes!WStartTime)

    EndTime = CDate(qryTimes!WEndTime)

    Origin = qryTimes!LocationID

    qryTimes.MoveNext

    Destination = qryTimes!LocationID

    Duration = #12:00:00 AM#

    tblInterval.MoveFirst


    Do Until tblInterval.EOF
```

```
  If tblInterval!ModeIDLabel = "m" And tblInterval!StatusID = "o" Then
    Interval_O = CDate(Format("00:" & tblInterval!Interval, "hh:mm:ss AM/PM"))
  ElseIf tblInterval!ModeIDLabel = "m" And tblInterval!StatusID = "p" Then
    Interval_P = CDate(Format("00:" & tblInterval!Interval, "hh:mm:ss AM/PM"))
  End If
tblInterval.MoveNext
Loop
Do While IntervalTime <= EndTime
    If (IntervalTime >= (CDate(qryTimes!FirstStart) - Interval_O) And IntervalTime <
    (CDate(qryTimes!FirstEnd) - Interval_P)) Or (IntervalTime >= (CDate(qryTimes!SecondStart) -
    Interval_O) And IntervalTime < (CDate(qryTimes!SecondEnd) - Interval_P)) Then
    qryDijkstra.MoveFirst
    StartTime = IntervalTime
    IntervalTime = IntervalTime + Interval_P
    Do Until qryDijkstra.EOF
    If qryDijkstra!IDFrom = qryDijkstra!IDTo - 1 And qryDijkstra!IDTo <= Destination And
    qryDijkstra!IDFrom >= Origin Then
        tblWeek1_45.AddNew
        tblWeek1_45!LocationID = qryDijkstra!IDFrom
        tblWeek1_45!DepartureTime = StartTime
        tblWeek1_45.Update
        Duration = CDate(Format("00:0" & qryDijkstra!Duration, "hh:mm:ss AM/PM"))
        StartTime = StartTime + Duration
      End If
    qryDijkstra.MoveNext
    Loop
  Else
   qryDijkstra.MoveFirst
    StartTime = IntervalTime
    IntervalTime = IntervalTime + Interval_O
    Do Until qryDijkstra.EOF
    If qryDijkstra!IDFrom = qryDijkstra!IDTo - 1 And qryDijkstra!IDTo <= Destination And
    qryDijkstra!IDFrom >= Origin Then
        tblWeek1_45.AddNew
```

```
            tblWeek1_45!LocationID = qryDijkstra!IDFrom
            tblWeek1_45!DepartureTime = StartTime
            tblWeek1_45.Update
            Duration = CDate(Format("00:0" & qryDijkstra!Duration, "hh:mm:ss AM/PM"))
            StartTime = StartTime + Duration
          End If
        qryDijkstra.MoveNext
        Loop
      End If
    Loop
  'Table population then the mode is "b"
  ElseIf qryTimes!ModeIDLabel = "b" Then
    StartTime = CDate(qryTimes!WStartTime)
    IntervalTime = CDate(qryTimes!WStartTime)
    EndTime = CDate(qryTimes!WEndTime)
    Origin = qryTimes!LocationID
    qryTimes.MoveNext
    Destination = qryTimes!LocationID
    Duration = #12:00:00 AM#
    tblInterval.MoveFirst
    Do Until tblInterval.EOF
      If tblInterval!ModeIDLabel = "b" And tblInterval!StatusID = "o" Then
        If tblInterval!Interval >= 60 Then
          Interval_O = Format(Round(tblInterval!Interval / 60, 0) & ":" & tblInterval!Interval Mod
          (Round(tblInterval!Interval / 60, 0) * 60), "hh:mm:ss AM/PM")
        Else
          Interval_O = Format("00:" & tblInterval!Interval, "hh:mm:ss AM/PM")
        End If
      ElseIf tblInterval!ModeIDLabel = "b" And tblInterval!StatusID = "p" Then
        If tblInterval!Interval >= 60 Then
          Interval_P = Format(Round(tblInterval!Interval / 60, 0) & ":" & tblInterval!Interval Mod
(Round(tblInterval!Interval / 60, 0) * 60), "hh:mm:ss AM/PM")
        Else
```

```
      Interval_P = Format("00:" & tblInterval!Interval, "hh:mm:ss AM/PM")
    End If
  End If
tblInterval.MoveNext
Loop
Do While IntervalTime <= EndTime
  If (IntervalTime >= (CDate(qryTimes!FirstStart) - Interval_O) And IntervalTime <
  (CDate(qryTimes!FirstEnd) - Interval_P)) Or (IntervalTime >= (CDate(qryTimes!SecondStart) -
  Interval_O) And IntervalTime < (CDate(qryTimes!SecondEnd) - Interval_P)) Then
    qryDijkstra.MoveFirst
    StartTime = IntervalTime
    IntervalTime = IntervalTime + Interval_P
    Do Until qryDijkstra.EOF
      If qryDijkstra!IDFrom = qryDijkstra!IDTo - 1 And qryDijkstra!IDTo <= Destination And
      qryDijkstra!IDFrom >= Origin Then
        tblWeek1_45.AddNew
        tblWeek1_45!LocationID = qryDijkstra!IDFrom
        tblWeek1_45!DepartureTime = StartTime
        tblWeek1_45.Update
        Duration = CDate(Format("00:0" & qryDijkstra!Duration, "hh:mm:ss AM/PM"))
        StartTime = StartTime + Duration
      End If
    qryDijkstra.MoveNext
    Loop
  Else
    qryDijkstra.MoveFirst
    StartTime = IntervalTime
    IntervalTime = IntervalTime + Interval_O
    Do Until qryDijkstra.EOF
      If qryDijkstra!IDFrom = qryDijkstra!IDTo - 1 And qryDijkstra!IDTo <= Destination And
      qryDijkstra!IDFrom >= Origin Then
        tblWeek1_45.AddNew
        tblWeek1_45!LocationID = qryDijkstra!IDFrom
        tblWeek1_45!DepartureTime = StartTime
```

```
          tblWeek1_45.Update
          Duration = CDate(Format("00:0" & qryDijkstra!Duration, "hh:mm:ss AM/PM"))
          StartTime = StartTime + Duration
        End If
      qryDijkstra.MoveNext
      Loop
    End If
  Loop
'Table population then the mode is "t"
ElseIf qryTimes!ModeIDLabel = "t" Then
  StartTime = CDate(qryTimes!WStartTime)
  IntervalTime = CDate(qryTimes!WStartTime)
  EndTime = CDate(qryTimes!WEndTime)
  Origin = qryTimes!LocationID
  qryTimes.MoveNext
  Destination = qryTimes!LocationID
  Duration = #12:00:00 AM#
  tblInterval.MoveFirst
  Do Until tblInterval.EOF
    If tblInterval!ModeIDLabel = "t" And tblInterval!StatusID = "o" Then
      Interval_O = CDate(Format("00:" & tblInterval!Interval, "hh:mm:ss AM/PM"))
    ElseIf tblInterval!ModeIDLabel = "t" And tblInterval!StatusID = "p" Then
      Interval_P = CDate(Format("00:" & tblInterval!Interval, "hh:mm:ss AM/PM"))
    End If
  tblInterval.MoveNext
  Loop
  Do While IntervalTime <= EndTime
     If (IntervalTime >= (CDate(qryTimes!FirstStart) - Interval_O) And IntervalTime <
    (CDate(qryTimes!FirstEnd) - Interval_P)) Or (IntervalTime >= (CDate(qryTimes!SecondStart) -
    Interval_O) And IntervalTime < (CDate(qryTimes!SecondEnd) - Interval_P)) Then
      qryDijkstra.MoveFirst
      StartTime = IntervalTime
      IntervalTime = IntervalTime + Interval_P
```

```
        Do Until qryDijkstra.EOF
          If qryDijkstra!IDFrom = qryDijkstra!IDTo - 1 And qryDijkstra!IDTo <= Destination And
          qryDijkstra!IDFrom >= Origin Then
            tblWeek1_45.AddNew
            tblWeek1_45!LocationID = qryDijkstra!IDFrom
            tblWeek1_45!DepartureTime = StartTime
            tblWeek1_45.Update
            Duration = CDate(Format("00:0" & qryDijkstra!Duration, "hh:mm:ss AM/PM"))
            StartTime = StartTime + Duration
          End If
        qryDijkstra.MoveNext
        Loop
      Else
        qryDijkstra.MoveFirst
        StartTime = IntervalTime
        IntervalTime = IntervalTime + Interval_O
        Do Until qryDijkstra.EOF
          If qryDijkstra!IDFrom = qryDijkstra!IDTo - 1 And qryDijkstra!IDTo <= Destination And
          qryDijkstra!IDFrom >= Origin Then
            tblWeek1_45.AddNew
            tblWeek1_45!LocationID = qryDijkstra!IDFrom
            tblWeek1_45!DepartureTime = StartTime
            tblWeek1_45.Update
            Duration = CDate(Format("00:0" & qryDijkstra!Duration, "hh:mm:ss AM/PM"))
            StartTime = StartTime + Duration
          End If
        qryDijkstra.MoveNext
        Loop
      End If
    Loop
  End If
qryTimes.MoveNext
Loop
```

```
End Sub
```

11.2.2 MODULE WEEK45_1

```
Public Sub Week45_1()
Dim gryTimes As Recordset
Set qryTimes = CurrentDb.OpenRecordset("qryTimes")
Dim qryDijkstra As Recordset
Set qryDijkstra = CurrentDb.OpenRecordset("qryDijkstraRev")
Dim tblInterval As Recordset
Set tblInterval = CurrentDb.OpenRecordset("tblInterval")
Dim tblWeek45_1 As Recordset
Set tblWeek45_1 = CurrentDb.OpenRecordset("tblWeek45-1")
Dim Interval_P As Date
Dim Interval_O As Date
Dim Origin As Integer
Dim Destination As Integer
Dim Duration As Date
Dim StartTime As Date
Dim EndTime As Date
Dim IntervalTime As Date
Do Until qryTimes.EOF
  If qryTimes!ModeIDLabel = "m" Then     'Table population then the mode is "m"
    Origin = qryTimes!LocationID
    qryTimes.MoveNext
    StartTime = CDate(qryTimes!WStartTime)
    IntervalTime = CDate(qryTimes!WStartTime)
    EndTime = CDate(qryTimes!WEndTime)
    Destination = qryTimes!LocationID
    Duration = #12:00:00 AM#
    tblInterval.MoveFirst
    Do Until tblInterval.EOF
      If tblInterval!ModeIDLabel = "m" And tblInterval!StatusID = "o" Then
        Interval_O = CDate(Format("00:" & tblInterval!Interval, "hh:mm:ss AM/PM"))
```

```
  ElseIf tblInterval!ModeIDLabel = "m" And tblInterval!StatusID = "p" Then
    Interval_P = CDate(Format("00:" & tblInterval!Interval, "hh:mm:ss AM/PM"))
  End If
tblInterval.MoveNext
Loop
Do While IntervalTime <= EndTime
  If (IntervalTime >= (CDate(qryTimes!FirstStart) - Interval_O) And IntervalTime <
  (CDate(qryTimes!FirstEnd) - Interval_P)) Or (IntervalTime >= (CDate(qryTimes!SecondStart) -
  Interval_O) And IntervalTime < (CDate(qryTimes!SecondEnd) - Interval_P)) Then
    qryDijkstra.MoveFirst
    StartTime = IntervalTime
    IntervalTime = IntervalTime + Interval_P
    Do Until qryDijkstra.EOF
      If qryDijkstra!IDFrom = qryDijkstra!IDTo + 1 And qryDijkstra!IDTo <= Destination And
      qryDijkstra!IDFrom >= Origin Then
        tblWeek45_1.AddNew
        tblWeek45_1!LocationID = qryDijkstra!IDFrom
        tblWeek45_1!DepartureTime = StartTime
        tblWeek45_1.Update
        Duration = CDate(Format("00:0" & qryDijkstra!Duration, "hh:mm:ss AM/PM"))
        StartTime = StartTime + Duration
      End If
    qryDijkstra.MoveNext
    Loop
  Else
    qryDijkstra.MoveFirst
    StartTime = IntervalTime
    IntervalTime = IntervalTime + Interval_O
    Do Until qryDijkstra.EOF
      If qryDijkstra!IDFrom = qryDijkstra!IDTo + 1 And qryDijkstra!IDTo <= Destination And
      qryDijkstra!IDFrom >= Origin Then
        tblWeek45_1.AddNew
        tblWeek45_1!LocationID = qryDijkstra!IDFrom
        tblWeek45_1!DepartureTime = StartTime
```

```
            tblWeek45_1.Update
            Duration = CDate(Format("00:0" & qryDijkstra!Duration, "hh:mm:ss AM/PM"))
            StartTime = StartTime + Duration
          End If
        qryDijkstra.MoveNext
        Loop
      End If
    Loop
'Table population then the mode is "b"
ElseIf qryTimes!ModeIDLabel = "b" Then
    Origin = qryTimes!LocationID
    qryTimes.MoveNext
    StartTime = CDate(qryTimes!WStartTime)
    IntervalTime = CDate(qryTimes!WStartTime)
    EndTime = CDate(qryTimes!WEndTime)
    Destination = qryTimes!LocationID
    Duration = #12:00:00 AM#
    tblInterval.MoveFirst
     Do Until tblInterval.EOF
      If tblInterval!ModeIDLabel = "b" And tblInterval!StatusID = "o" Then
        If tblInterval!Interval >= 60 Then
          Interval_O = Format(Round(tblInterval!Interval / 60, 0) & ":" & tblInterval!Interval Mod
          (Round(tblInterval!Interval / 60, 0) * 60), "hh:mm:ss AM/PM")
        Else
          Interval_O = Format("00:" & tblInterval!Interval, "hh:mm:ss AM/PM")
        End If
      ElseIf tblInterval!ModeIDLabel = "b" And tblInterval!StatusID = "p" Then
        If tblInterval!Interval >= 60 Then
          Interval_P = Format(Round(tblInterval!Interval / 60, 0) & ":" & tblInterval!Interval Mod
          (Round(tblInterval!Interval / 60, 0) * 60), "hh:mm:ss AM/PM")
        Else
          Interval_P = Format("00:" & tblInterval!Interval, "hh:mm:ss AM/PM")
        End If
```

```
  End If
tblInterval.MoveNext
Loop
Do While IntervalTime <= EndTime
   If (IntervalTime >= (CDate(qryTimes!FirstStart) - Interval_O) And IntervalTime <
   (CDate(qryTimes!FirstEnd) - Interval_P)) Or (IntervalTime >= (CDate(qryTimes!SecondStart) -
   Interval_O) And IntervalTime < (CDate(qryTimes!SecondEnd) - Interval_P)) Then
     qryDijkstra.MoveFirst
     StartTime = IntervalTime
     IntervalTime = IntervalTime + Interval_P
     Do Until qryDijkstra.EOF
       If qryDijkstra!IDFrom = qryDijkstra!IDTo + 1 And qryDijkstra!IDTo <= Destination And
       qryDijkstra!IDFrom >= Origin Then
         tblWeek45_1.AddNew
         tblWeek45_1!LocationID = qryDijkstra!IDFrom
         tblWeek45_1!DepartureTime = StartTime
         tblWeek45_1.Update
         Duration = CDate(Format("00:0" & qryDijkstra!Duration, "hh:mm:ss AM/PM"))
         StartTime = StartTime + Duration
       End If
     qryDijkstra.MoveNext
     Loop
  Else
     qryDijkstra.MoveFirst
     StartTime = IntervalTime
     IntervalTime = IntervalTime + Interval_O
     Do Until qryDijkstra.EOF
       If qryDijkstra!IDFrom = qryDijkstra!IDTo + 1 And qryDijkstra!IDTo <= Destination And
       qryDijkstra!IDFrom >= Origin Then
         tblWeek45_1.AddNew
         tblWeek45_1!LocationID = qryDijkstra!IDFrom
         tblWeek45_1!DepartureTime = StartTime
         tblWeek45_1.Update
         Duration = CDate(Format("00:0" & qryDijkstra!Duration, "hh:mm:ss AM/PM"))
```

```
            StartTime = StartTime + Duration
          End If
        qryDijkstra.MoveNext
        Loop
      End If
    Loop
'Table population then the mode is "t"
ElseIf qryTimes!ModeIDLabel = "t" Then
    Origin = qryTimes!LocationID
    qryTimes.MoveNext
    StartTime = CDate(qryTimes!WStartTime)
    IntervalTime = CDate(qryTimes!WStartTime)
    EndTime = CDate(qryTimes!WEndTime)
    Destination = qryTimes!LocationID
    Duration = #12:00:00 AM#
    tblInterval.MoveFirst
    Do Until tblInterval.EOF
      If tblInterval!ModeIDLabel = "t" And tblInterval!StatusID = "o" Then
        Interval_O = CDate(Format("00:" & tblInterval!Interval, "hh:mm:ss AM/PM"))
      ElseIf tblInterval!ModeIDLabel = "t" And tblInterval!StatusID = "p" Then
        Interval_P = CDate(Format("00:" & tblInterval!Interval, "hh:mm:ss AM/PM"))
      End If
    tblInterval.MoveNext
    Loop
    Do While IntervalTime <= EndTime
      If (IntervalTime >= (CDate(qryTimes!FirstStart) - Interval_O) And IntervalTime <
       (CDate(qryTimes!FirstEnd) - Interval_P)) Or (IntervalTime >= (CDate(qryTimes!SecondStart) -
       Interval_O) And IntervalTime < (CDate(qryTimes!SecondEnd) - Interval_P)) Then
        qryDijkstra.MoveFirst
        StartTime = IntervalTime
        IntervalTime = IntervalTime + Interval_P
        Do Until qryDijkstra.EOF
```

```
          If qryDijkstra!IDFrom = qryDijkstra!IDTo + 1 And qryDijkstra!IDTo <= Destination And
          qryDijkstra!IDFrom >= Origin Then
            tblWeek45_1.AddNew
            tblWeek45_1!LocationID = qryDijkstra!IDFrom
            tblWeek45_1!DepartureTime = StartTime
            tblWeek45_1.Update
            Duration = CDate(Format("00:0" & qryDijkstra!Duration, "hh:mm:ss AM/PM"))
            StartTime = StartTime + Duration
          End If
        qryDijkstra.MoveNext
        Loop
      Else
        qryDijkstra.MoveFirst
        StartTime = IntervalTime
        IntervalTime = IntervalTime + Interval_O
        Do Until qryDijkstra.EOF
          If qryDijkstra!IDFrom = qryDijkstra!IDTo + 1 And qryDijkstra!IDTo <= Destination And
          qryDijkstra!IDFrom >= Origin Then
            tblWeek45_1.AddNew
            tblWeek45_1!LocationID = qryDijkstra!IDFrom
            tblWeek45_1!DepartureTime = StartTime
            tblWeek45_1.Update
            Duration = CDate(Format("00:0" & qryDijkstra!Duration, "hh:mm:ss AM/PM"))
            StartTime = StartTime + Duration
          End If
        qryDijkstra.MoveNext
        Loop
      End If
    Loop
  End If
qryTimes.MoveNext
Loop
End Sub
```

11.3 CONTENT OF ATTACHED CD

The attached CD contains the following files:

- The CoCT's transport data list.
- The CSV files of the coordinates used in modelling the multimodal supernetwork.
- Dijkstra's routing algorithm implemented in Microsoft Excel.
- The PowerPivot application for Microsoft Excel 2010.
- The PowerPivot of the exported Microsoft Access database.
- The timetables exported from Microsoft Access to Microsoft Excel.