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Spatial information system for public transport

Submitted to the University of Cape Town in fulfilment of the
requirements of Degree of Master of Science in Engineering

by

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Dedication

To my Mother and Father for bringing me into this world and making me the person that I am today.

To my husband, his family and my family for being supportive throughout this work.

To Ellen, Chido, Tafadzwa, Rumbidzai, Ruvimbo.

May God bless you all.

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Abstract

One way of reducing traffic congestion is through the promotion of public transport over private cars. Many countries, South Africa included, have set up policies to prioritise this issue. In accordance with these policies, public transport service planners are working to improve public transport services. This requires the collection of data on public transport usage, public transport timetables and the location of the routes, stops and termini. This data needs to be managed and integrated for use in decision-making on public transport services planning. As some of the data is spatial in nature, a spatial information system is proposed as the best tool for capturing, storing and analysing the data.

To accurately represent the data in the spatial information system database, a data model is required. The data model in this research is designed using the object-relational model in ESRI ArcInfo Version 8.2. Another challenge lies in how to represent the spatial data in the systems. In this research, the roads are represented as network features, the stops and the public transport routes are treated as point and line features respectively. The routes are modelled by a process called dynamic segmentation, which allows multiple attributes to be associated with a sections of the route.

The prototype data model is implemented for Blaauwberg, in Cape Town. A stand-alone application is developed using ESRI MapObjects Version 2.0 and Microsoft Visual Basic 6.0 to enable easy retrieval of information from the database.

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Glossary of terms

Spatial information system (SIS)/ Geographical Information Systems (GIS)	A system for capturing, storing, manipulating, analysing and displaying spatially referenced data.
A data model	A representation of the real world and reflects decisions about what features and relationships are necessary to represent in the database.
A database	A collection of digital data with a given structure for accepting, storing, and providing, on demand, data for multiple users.
A geodatabase	An ArcInfo 8 data format used for storing information. It is a short name for a geographic database.
Public transport/Transit	Services provided for the carriage of passengers and their incidental baggage within cities and metropolitan areas, usually on a fare-paying basis. Examples include buses, minibus taxis and trains.
Passenger	A person, other than the operator, who is making use of transport for the purpose of being transported.
User Interface	Refers to methods and devices that enable communication between human beings and computers.
Peak Hour	The interval of one hour giving the greatest volume of traffic in the given period of time.
Network	A two-dimensional representation of the layout of a transport system.
Spatial database Engine (SDE)	A geographic database product that provides a spatial extension to an underlying commercial relational database management system (RDBMS), thereby enabling all data (spatial and non-spatial) to be stored within a single RDBMS.
Structured Query Language (SQL)	The standard language for querying and manipulating relational databases.
Unified Modelling Language (UML)	A standard set of symbols and diagrams to specify, construct, and document systems that use object-oriented

code.

SQL Server®

A relational database and analysis system developed by Microsoft that can be used to provide extensive database facilities on a web site.

CASE Tools

A computer based product aimed at supporting the work of a system developer creating models and other system documents and components.

Mode

The means by which a person or a group of people make a trip.

Freeway

A dual carriageway road whose only function is movement and carrying high speed or bypass traffic.

Terminus

A special area, including buildings, structures and equipment at the end of a transport facility, for the storage, transfer, handling and reception of vehicles, passengers and materials.

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Chapter One

Introduction

1. Background

Traffic congestion is one of the major problems plaguing urban cities all over the world today. With traffic congestion, goods and services are slow to market and employees are late for work. This results in reduced production. At the same time, idling vehicles waste fuel and cause air pollution. In South Africa, millions of Rands are lost each year on congestion costs (CERF 1999). Some of the costs include; costs due to reduced production in companies because of unnecessary delays caused to employees on their way to work, vehicle operating and fuel costs, road damage cost, and pollution costs (Maddison *et al* 1996).

Much of the traffic congestion in South Africa can be attributed to private vehicles because it is a private car-dominated country (CERF 1999). According to the South Africa Survey for the year 2000/2001, about 19% of the urban population uses private cars. Although this is still low compared to developed countries, which have about 50% of their population using the private car, the situation should be rectified before the adverse effects associated with the use of private cars are experienced.

Studies carried out in Cape Town, project that if no immediate action is taken to reduce traffic congestion, by the year 2020 the car population will increase by 64%, thereby reducing highway traffic speeds to 29 kilometres per hour. It is not clear whether the road infrastructure will be sufficient to cater for these increases in private cars or whether there will be enough financial resources to upgrade the existing road infrastructure. Highways are already congested during peak hours, as can be witnessed when one is travelling on the streets of any major town in South Africa (de Saint Laurent 1998, National Department of Transport 1999, Forgey *et al* 2001).

As a solution to the congestion problems, policies in many countries worldwide, including South Africa, are shifting towards the promotion of public transport usage

over the use of private cars (Climate change 2001). As public transport has a better cost and space effectiveness for the transportation of volumes of people, having more people use public transport will lead to a reduction in the number of vehicles on the road. This will, in turn, reduce traffic congestion and its effects (de Saint Laurent 1998).

This is, however, not as easy as it sounds. Public transport is unpopular with users for various reasons. Some of them include the unpredictability of transport schedules and the lack of adequate information on services, frequencies, costs and transfer opportunities from one transport mode to another (McQueen *et al* 1999 and Tiwari 2001).

In South Africa, according to studies carried out in Cape Town and Durban, some of the reasons why people prefer private cars to public transport are (Clark *et al* 2001, Lombard *et al* 2001, Pillay 2001, Botes *et al* 2001):

- ❑ Most public transport vehicles are aged and unroadworthy, making them more susceptible to accidents;
- ❑ Public transport services are unreliable and slow;
- ❑ There is a lack of services during off peak periods to cater for tourists, students and other people likely to travel at that time of day;
- ❑ Public transport users experience long travel times as a result of too many stops along the way, as some of the vehicles stop at undesignated points;
- ❑ Public transport users have to walk long distances to get to the nearest public transport stop or terminus;
- ❑ There are notable differences in fares for different public transport modes; and
- ❑ Public transport vehicles get over-crowded during peak times.

In order to dissuade people from private car use to public transport, public transport has to offer the same flexibility as private cars (Wendell Cox 1996), and the unattractive characteristics associated with public transport, mentioned above, must be removed. This has been the goal of many public transport service planners worldwide.

However, before any improvements can be made, public transport planners need to assess what exactly the local characteristics are, how serious the situation is and what

effects negative characteristics have on the usage of public transport. They need to gather the necessary data to assess the situation, which would include data on the public transport services available and the amount of people using public transport.

To collect this data, public transport surveys have to be carried out. Examples of these surveys include the study of ticket issuing records, on-board transit surveys¹, passenger counting at termini and ride check surveys (Macpherson 1993, Salter *et al* 1996, Simmons *et al* 2001, Ortúzar *et al* 1994). In Cape Town examples of the methods used to collect public transport usage data are the passenger counting at termini and ride check surveys (Moving Ahead 2001). The surveys of special concern in this discussion are ride check surveys, because the data from these surveys is to be included in this research's spatial information system.

Traditionally, during ride check surveys carried out by the Cape Metropolitan Council in Cape Town, a surveyor would be placed in a public transport vehicle for the duration of a trip. The surveyor would manually record the number of passengers getting on and off at each stop and the method used for ticket payment. This would present a problem when the vehicle stops at any place that is neither an existing stop nor a terminus. There would be no location information on that stop available in the database. Any attempts to represent such a place on a map results in an inaccurate representation because an approximate position is used. Sometimes, when visibility is poor, the surveyor would find it difficult to read off the stop number from the stop shelter in the short time that the vehicle stops to drop off or pick up passengers. The manual recording of the arrival and departure times at each stop and the counting of the people getting on and off the vehicle would also result in inaccurate data due to human error and fatigue.

Due to the above-mentioned errors, the situation has since changed. A surveyor now has to carry a global positioning system (GPS) receiver and a palmpilot² onto the public transport vehicle. The GPS receiver collects location information of each of the stops

¹ Questionnaires are distributed to passengers during a trip and they fill in their origins, destinations, purposes and some aspects of their travel. They can submit the questionnaire at the end of the trip or it can be mailed or collected later.

² A palmpilot is a small handheld computer used for task scheduling and note taking.

and the palmpilot electronically records all the data gathered. In a recent survey carried out in 2000, at every stop, the surveyor recorded the following data (AfriGIS 2000):

- The position of the stop in terms of x and y co-ordinates;
- The arrival and departure time at the stop;
- The number of passengers boarding and alighting; and
- The method of payment used, whether cash or clip card, for the ticket.

1.1. Problem statement

For the ride check surveys carried out by the Cape Metropolitan Council Department of Transport in the year 2000, after the data was captured on palmpilots in the field, it was downloaded into Microsoft Excel spreadsheets on computers back in the office. Up to 80 megabytes of data were generated for each mode of public transport and these created over a thousand spreadsheets for each mode. Some of the spreadsheets contained no data in cases where the vehicle for a particular route and time did not take the scheduled trip.

The main problem was in effectively managing this data in a structured way by minimising data redundancy and thereby reducing the amount of space required for storage in the computer and providing easy access as and when required. There was also lack of a user-friendly tool for the efficient processing and analysis of this voluminous data in order to extract meaningful information for decision support on planning and development of public transport infrastructure and services.

According to literature and interviews carried out by officials from the Cape Metropolitan Council, decision-makers require the following public transport information for planning:

- The amount of people using the termini and bus stops and how easily accessible these facilities are to the public;
- The amount of people using the public transport vehicles;
- Whether the public transport vehicles are adhering to schedule and any delays experienced during travel; and
- How well the existing infrastructure and facilities are serving the public transport users.

This information is obtained after the data from surveys, such as the one explained in Section 1, is processed and analysed. As public transport data is spatial in nature and the Cape Metropolitan Council Department of Transport department also required the resulting information to be presented in graphical form, this research proposes the use of spatial information system in efficiently managing, storing, integrating, displaying and analysing the data for planning and modelling purposes (Zhong 1998a, Papacostas *et al* 1993, Etches *et al* 2000).

A spatial information system effectively manages and also enables regular updates to the public transport information, which are essential considering that it is constantly changing. Usually, when the transport information is not managed efficiently in a structured way, updates are difficult to perform and this often leads to the use of outdated and misrepresentative information in the planning process. In some cases, some vital information may be omitted from the planning process. This leads to improvements or developments that have no impact on the potential user leading to public transport maintaining its unpopularity. A good example is in Durban, where poor planning for bus routes and bus stops resulted in some bus stations being located far from residential areas. The public transport users have to travel long distances to the nearest bus stop or station. This has led to public transport becoming less attractive and people preferring other modes of transport like the private car (Lombard *et al* 2001).

The results and effects of not efficiently managing data can be summarised into a diagram (see Figure 1.1)

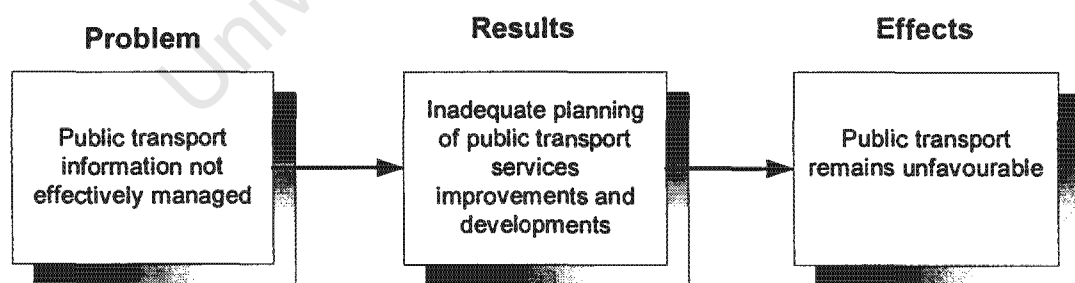


Figure 1.1: Ineffective management public transport information

After considering the above-mentioned problem and its effects, the main objective and specific objectives of this research were formed. These are presented in the following section.

1.2. Research objectives

1.2.1. Main objective

To develop a prototype spatial information system for public transport information management.

1.2.2. Specific objectives

- Design of a data model for the spatial information system for public transport information management.
- Implementation of the data model for a prototype system for Blaauwberg Municipality, Western Cape Province, South Africa.

1.3. Research questions

To fulfil the objectives mentioned above, the following research questions have to be answered:

- What kind of public transport information has to be managed and how is it acquired?
- What are the different approaches used in creating data models for public transport information management, which data model is to be used and why?
- Which geographic information software is to be used and how are the physical databases created and features represented in this software?
- Does the software allow for any customisation if necessary?

1.4. Area of study

Blaauwberg, in the Western Cape Province in South Africa (a map of which is shown in Figure 1.2).

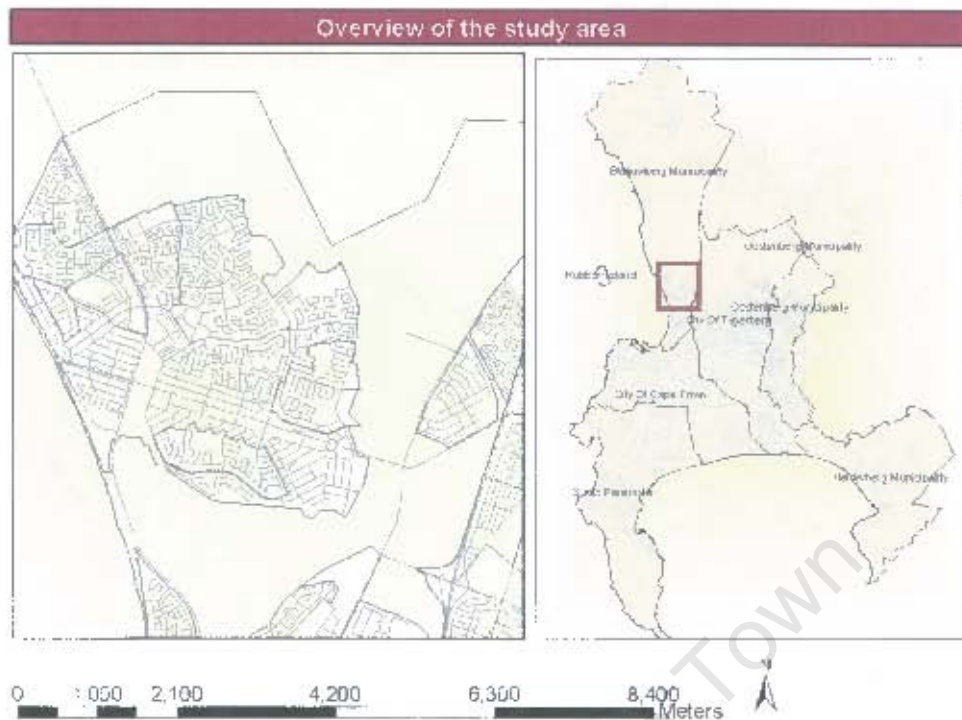


Figure 1.2: Map of Blaauwberg, the study area⁵

1.5. Scope of the research

Although this thesis investigates the use of spatial information system for public transport, the main focus lies in developing the data model.

Throughout the research up to the data model design phase, the discussion will be in relation to all public transport modes but due to time limitations, only one mode of public transport will be selected for the implementation of the data model.

If a functional prototype system, providing the required information as was stated in Section 1.1, is developed based on sound theoretical principles of data model design, it will be assumed to be effective for managing public transport information. Therefore, the only aspect of the prototype system that needs to be tested is how user-friendly it is.

⁵ The inset contains a map of Cape Town with the position of Blaauwberg in relation to Cape Town being highlighted by the brown box.

1.6. Expected use of output

In the White Paper on National Transport Policy in 1996, the government of South Africa placed emphasis on the improvement of public transport services. The Western Cape Province, in South Africa has written its own White Paper on Transport for the province echoing similar sentiments. To date, both the government and the provincial council are still designing strategies to achieve this. This research aims to contribute to these strategies by offering a spatial information system that can be implemented throughout the Western Cape for various types of public transport.

1.7. Thesis outline

Chapter One gives background information on the research area. The objectives of this research and the area to be used to implement the prototype are also stated.

Prior to the undertaking of any research there must be a study of similar work done on that particular research area, any methods used that can be adopted or any gaps that can be filled. This is provided by the literature review in *Chapter Two*. This chapter also gives examples of applications of spatial information system in public transport.

Chapter Three looks at the stages involved in designing a spatial information system. From this discussion, recommendations are made and these assist in developing the prototype spatial information system for this research.

Chapter Four shows the design and implementation of the data model in the relevant software and for the study area mentioned in Section 1.4.

Chapter Five explains some of the functions of the prototype system and how the possible queries can be performed.

Chapter Six presents conclusions and analysis of the results obtained from the software testing carried out by selected transport professionals. Finally, recommendations for future research are provided.

Chapter Two

Literature Review

2. Introduction

This chapter highlights current worldwide trends in the use of spatial information systems for public transport. Typical applications and examples of systems developed under each application are provided. The discussion restricts to applications of relevance to the South Africa situation, which is presented after the discussion of the applications. Most of the theoretical concepts involved are mentioned in this chapter and fully discussed in later chapters. A point to note is that the words Geographical Information Systems (GIS)⁴ and spatial information systems have the same meaning in this research document.

2.1. The use of spatial information systems in public transport

Spatial information systems are a system for capturing, storing, manipulating, analysing and displaying spatially referenced data. The first use of spatial information systems in transport dates back to the 1960s, but by the late 1980s, its use was more widespread (Thill 2000, Goodchild 1999, Souleyrette *et al* 2000).

Spatial information systems allow the integration of spatial and attribute data by referencing all objects and data to a common geographical location framework. Due to the fact that spatial information systems support the development of user friendly graphic user interfaces (GUIs), the integrated layers of data can be presented on a user-friendly GUI, for use by public transport planners in analysis and scenario modelling to determine where and when to make improvements or new developments (Thill 2000, Shepherd *et al* 1991, Flowerdew *et al* 1991, Goodchild 1996, Miller *et al* 1996, Thompson 1999).

⁴ GIS can be defined as a system for capturing, storing, manipulating, analysing and displaying spatially referenced data.

Visualisation is one of the most important applications of spatial information systems. A lot of software products are utilised in public transport planning and modelling, but most of them output the information in database format, with descriptions in words and numbers. Clearly, this type of information requires an expert in the area to decipher, analyse and draw conclusions from. With spatial information systems, public transport planners can display information on the number of passengers boarding and alighting by time of day at each stop, for every route or per sections of the route. This enables them to evaluate the performance of public transport services. Public transport planners are also able to identify the demographic and land use characteristics within walking distance of a proposed route and hence estimate ridership statistics (Zhong *et al* 1998b, Alterkawi 2001, Schweiger 1992).

Most transport developments or constructions rely on funds from the government and other private companies. This means that even when transport planners perform their analysis and determine where new routes are to be constructed or where improvements should be made, ultimately, they have to convince government and private company officials to support them financially. This requires the presentation of analysis results visually in terms of graphs, charts or maps that everyone can easily visualise and understand (Attanucci *et al* 1999, Goodchild 1996, Drane *et al* 1998).

Section 2.2 discusses the applications of spatial information systems in public transport, with examples being provided for each application.

2.2. Applications of SIS in public transport

The following are typical applications of spatial information systems in public transport:

- ❑ Facilities inventory and data management;
- ❑ Ridership analysis and reporting;
- ❑ Transit schedule monitoring;
- ❑ Transit route planning and market analysis; and
- ❑ Passenger information systems.

2.2.1. Facilities inventory and data management

Facilities inventory and data management is concerned with the management of data on the public transport facilities and services. An example is the Durban Public Transport Management Information System (PTMIS). This system is well documented and uses spatial information system in public transport facilities inventory and data management in Durban, South Africa. Louw *et al* (2001) documented its development. The software used was ESRI ArcView Version 3.2 ®.

The development of this system was prompted by the fact that information on public transport services and facilities was stored in various sources, in different formats and maintained by different operators. This made decision-making for planning purposes difficult.

The PTMIS provided simulations for a Stated Preference Study, which was carried out to test the reactions of public transport users to any changes made to public transport services. The study resulted in the creation of a public transport user preferred model. The preferred model was tested using the EMME/2® software (a tool for transport modelling), which simulated demand patterns and displayed them on a GIS map in the PTMIS. This information assists decision-makers in planning for the restructuring of public transport in the city.

The PTMIS generates reports with information on passenger volumes, public transport route descriptions, capacity, utilisation, routes, fares and timetables per section of a route. Information is categorised as bandwidths by time, operator and mode. It also displays or generates public transport origin-destination information by selected origin-destination sub-sections.

The PTMIS stores and displays taxi rank layouts, drawings and daily bus operations using video clips. An economic model is available to display the economic feasibility of developing a new route. There is also an extension for capturing, editing and displaying information from the EMME/2® transport modelling processes. Figure 2.1 shows the PTMIS user interface.

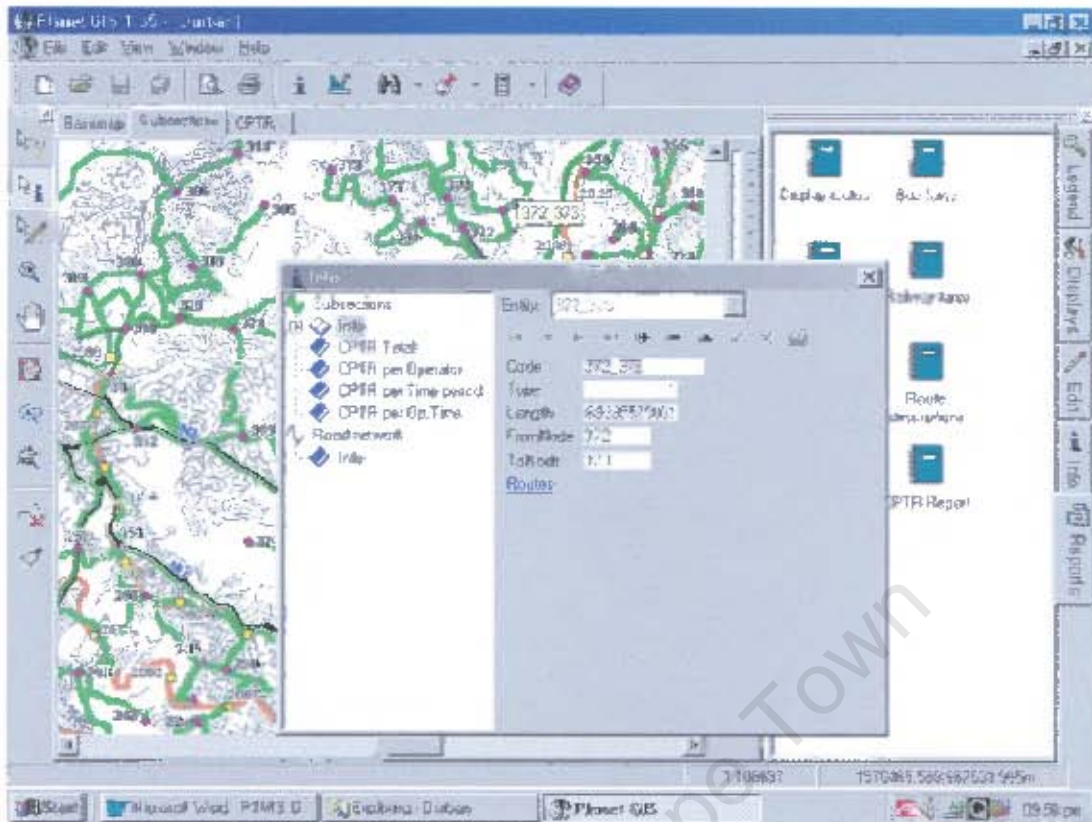


Figure 2.1: The PTMIS user interface (Louw *et al* 2001)

Public transport services in South Africa have been described as not fully meeting users' needs. This is as a result of operators planning for services in isolation without taking into account other operators, services and modes of transport (Britz *et al* 2001, Aucamp *et al* 2001). Having information on all the different modes of transport in one database, as in the Durban PTMIS, means that all the operators and services are taken into consideration and therefore planning is improved.

2.2.2. Ridership analysis and reporting

Ridership analysis and reporting involves the analysis of the amount of people using transit services and the output of the information in a suitable format (mostly graphical) for decision-makers and planners. An example is the use of spatial information systems in planning, production and analysis of public transportation by the Copenhagen Transport Company (Geitner *et al* 1999).

The database was designed using the relational model and the software products used were ESRI ArcView® and ESRI SDE® for SQL Server®. The system stores information relating to buses and trains. All the information is maintained on a server, and the users access it via a network.

Functions of the system include the provision of information on the number of people boarding and exiting at each stop, the average speeds of buses along particular routes and the service timetables. This information can be output as graphs or maps.

Figure 2.2 shows an interface of the system. The black dots of varying widths represent the amount of passengers either boarding or getting off the bus for each service. The larger the dots, the more the passengers indicated. The brown lines of varying thickness show the amount of passengers travelling along the sections of a route. The thickness of the line is directly proportional to the number of passengers.

The visual representation of the number of passengers exiting or entering at each stop or using each section of a route is commended. This assists the service planners to easily see uneven distributions in the trips.

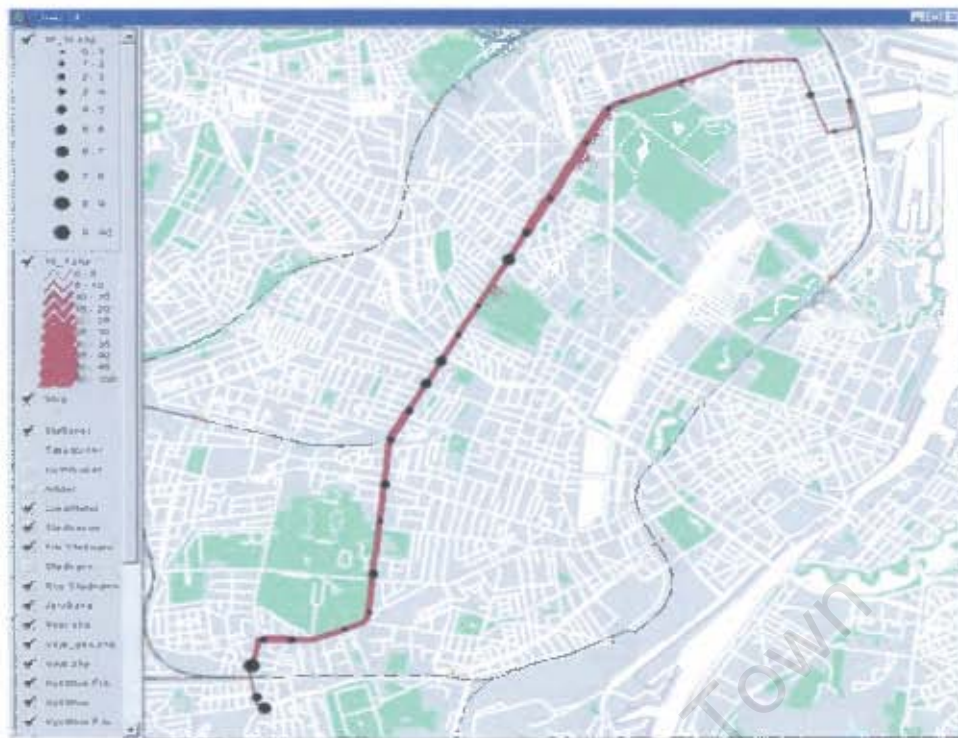


Figure 2.2: A Copenhagen Transport Company system user interface (Geitner *et al* 1999)

The main problem experienced with such a system is version management and reconciliation. Since the data is located on a server, if two people edit the same data from different computers at the same time, one can unknowingly overwrite the edits made by the other person. This is one of the limitations of using the relational model in creating databases; it does not offer version management capabilities (the rest of the limitations are discussed in Chapter Three). An attempt can be made to prevent the updating of data that is being processed by another transaction by a locking mechanism that guarantees exclusive access to a database item. This however presents problems if the database items become large.

2.2.3. Transit schedule monitoring

Transit scheduling involves all activities necessary to monitor whether the transit vehicles are all moving to the preset timetable and if not, assessing the situation and making the necessary improvements to the operation of transit vehicles or services.

An example is the use of spatial information systems for the monitoring of bus operations for Oahu Transit Services in Honolulu (Papacostas 1995). The system was

implemented using the ESRI ArcInfo® software. The development of this system focused on the use of ride check survey data, in a spatial information system, in monitoring the timetable schedule adherence of buses.

The ride check survey data was originally stored digitally as text files. The bus routes were created using the process of dynamic segmentation⁵, and bus stops are events⁶ of the route. In order to include the ride check survey data in a GIS, a key⁷ is assigned to each vehicle and each vehicle is assigned to a particular route. Each key is then assigned a number of runs on that route. As a result, a code consisting of the route number, the key and the run of that key uniquely identifies a bus-trip. Each bus-trip file contained the information illustrated in Table 2.1.

Table 2.1: The bus trip file

Date of survey	Checker name	Route	Direction	Key and run	BusID number	Seating capacity
----------------	--------------	-------	-----------	-------------	--------------	------------------

A separate file contained a list of all bus stops and ride check survey data (see Table 2.2).

Table 2.2: The bus stop and ride check data file

BusStopID	Passengers getting off	Passengers boarding	Arrival time
-----------	------------------------	---------------------	--------------

Figure 2.3 shows the user interface for the system.

⁵ Dynamic segmentation allows multiple sets of attributes to be associated with any portion of a linear feature. It is explained further in Chapter Five.

⁶ Events are used to model data along a route.

⁷ A key is a user defined unique identifier

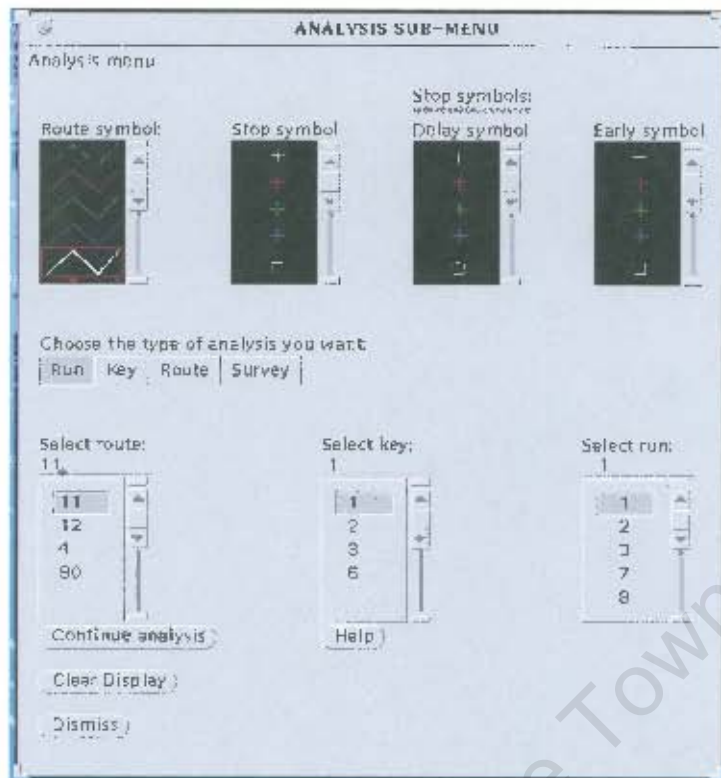


Figure 2.3: The system's user interface (Papacostas 1995).

The graphic user interface is user-friendly and this is an important aspect of any system. This ensures that even someone who is not an expert in the area can easily learn how to use the system. If the system is not user-friendly, most employees soon abandon it and go back to their previous ways of performing tasks putting all the resources involved in the design process to waste.

The use of dynamic segmentation is recommended for representing routes because attributes usually vary along any one route. If the trip file is used to represent data in the database, it leads to data redundancy⁸. This is due to the many-to-many relationships between the bus and the route, in the case where many buses use the same route.

Despite the ability to offer capabilities for analysis through interpretation of the attribute data, a GIS should also provide functionality for analysis by visual representation. According to Shaw (1999) and Wang *et al* (2001), it is important to represent the bus

⁸ Data redundancy is the duplication of data amongst files. Redundant data can be removed without the loss of any information.

trips paths visually. This assists when representing the number of travellers in a specific trip, for planning purposes. The system does not provide this functionality.

2.2.4. Transit route planning and market analysis

Market analysis involves the marketing of transit services by analysing service improvements and presenting the results to the public. Typical transit route planning activities include; linking passenger count data to transit route data to analyse the productivity of specific routes and analysing the travel characteristics of transit users in order to determine the prospective for bus services.

An example is the system used by the Orange County Transportation Authority (OCTA), in California. It uses a spatial information system to perform market analysis, transit route analysis and evaluate potential changes to the existing transit service and therefore determine how service changes can affect ridership (FHWA 2000).

Figure 2.4 shows the results of an accessibility analysis for selected stops. Accessibility analyses are carried out to determine the amount of people living within walking distance to each of the stops. Those people further from the stops will necessitate the erection of stops closer to their homes or the creation of new routes.



Figure 2.4: OCTA accessibility analysis results.

At the time the report was written, the transport authority was managing a fleet of 400 buses with approximately 1 300 riders per day. The software products used in planning and market analysis are ESRI ArcInfo® and ArcView®.

2.2.5. Passenger information system

Passenger information system involves the provision of information to the public on transit service timetables, routes and fares. This information can be provided either by phone, e-mail or via the Internet. Spatial information systems assist in processing the data and displaying the results on a map. An example is the web-based information system developed for the Champaign-Urbana Mass Transit District (CUMTD) bus service (Lee *et al* 1999).

The system has two components, the phone in component and the web-based component. The initial web-based prototype system was developed using ESRI Arc/Info Version 7.1.2 and AML⁹ but due to the fact that the software did not support web capabilities, ESRI MapObjects 1.2® and ESRI MapObjects Internet Map Server (IMS) 2.0® were used. The bus stop, bus route and schedule tables were linked using the relational model.

The phone in component enables members of the community to phone in to the operator and provide details for their origins and destinations and the time they want to travel. The operator then selects the suitable route and time for the caller and provides the information to them.

In the web component, the users logs onto the website, enters their origin and destination and the program calculates the shortest path and displays the result on a map (see Figure 2.5).

⁹ Arc/Info Macro Language and is used for customising the software.

Step 4: Verifying Your Selection

Note: Origin and Destination selections made by address or landmark are approximate and may not reflect the exact location.

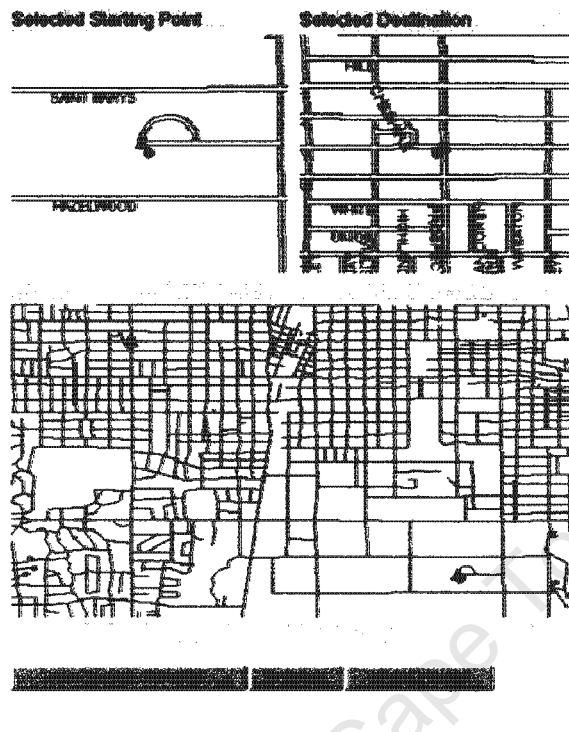


Figure 2.5: CUMTD interface for the shortest route (Lee *et al* 1999)

The main challenge in implementing such a system is the high costs involved in data acquisition. This is due to the fact that the input spatial and attribute data has to be very accurate and should be updated regularly to reflect any changes in the road network. Other challenges include the need to supply descriptive information on each bus stop for it to be familiar with the users, as the use of numbers or identifiers would confuse them.

2.3. The South African situation

In Chapter One, section 1, some of the unfavourable characteristics of public transport in South Africa are stated. These have been attributed to inadequate transport planning and development practices from the apartheid era, which promoted racial separation and caused disparities in the quality of service. The new government saw the need to change these practises through the establishment of policies and legislation. These include the White Paper for National Transport Policy in 1996, followed by the Moving South Africa 2000 and the National Land Transport Transition Act Number 22 of 2000 (NLTTA).

Entrenched in the White Paper for National Transport Policy, Moving South Africa and the NLTTA are policies, among other, that advocate for:

- The maximisation of the speed and service of passengers;
- The provision of on-line information to the transport users to enable them to make their choice of which mode to use;
- The increase of safety during transportation;
- The integration of different modes of transport;
- The annual creation of a Current Public Transport Record (CPTR), which contains the status quo of public transport services, facilities and usage and a statutory requirement is for the CPTR to contain a map of the facilities. For the CPTR, some spatial analyses are required to determine average walking distances to bus stops or routes and the relationship between socio-economic characteristics/land use and public transport activity.

From the policies set out in this legislation, it can be concluded that all the applications of spatial information systems in public transport explained in Section 2.2, which are mostly from developed countries, are relevant and can be implemented in South Africa and also lead to the fulfilment of the objectives set from the policies. As a result, spatial information system software products are commonly used in public transport in most of the Metropolitan areas' transport departments.

In attempting to assess the applications already in use and how they are developed, the main problem encountered is that of limited availability of published literature. For example, in this research, the only published literature obtained was that of the Durban Public Transport Information System discussed in Section 2.2.1. Many of the applications only become apparent when one conducts interviews or visits to the respective departmental offices.

Only after conducting visits or interview can the challenges faced in using spatial information systems be ascertained. These include the failure of the systems, in some cases, to handle other types of data, especially the data acquired from public transport surveys, or to perform required functions. The main cause of this problem is that when

many departments engage in spatial information system applications, there is lack of forethought on the particular functions to be performed and also how other databases can interface with the application. Another cause is that of lack of expertise to develop the databases when software products are purchased. The data is used in the software without a structured database. At a later stage, when some functions are required or when some other type of data needs to be used in the software, difficulties are encountered and only then are consultants engaged and a proper database structure is established.

2.4. Summary

The systems that have been reviewed in this chapter illustrate the typical applications of spatial information systems in public transport. What they all have in common is that their databases were developed using the relational model, as it is the model supported by ESRI ArcView 3.2®, ArcInfo 7.5.1® and MapObjects 2.0®, which, as is discussed in Chapter Three, has limitations when representing the complex data handled in spatial information systems.

Chapter Three outlines the stages involved in designing a spatial information system, with particular focus on the data model design stage.

Chapter Three

The design of a spatial information system

3. Introduction

This chapter discusses the main phases in developing a spatial information system. More detail is provided for the data model design phase, as it is the most important phase and the main focus of this research. The diagram in Figure 3.1 highlights the main phases in designing a spatial information system.

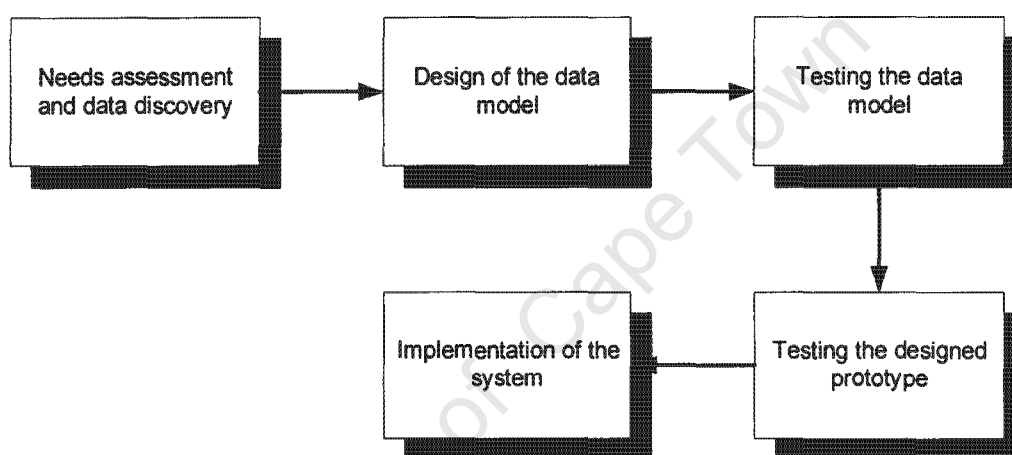


Figure 3.1: The phases in designing a spatial information system

The first phase in designing a spatial information system is for needs assessment and data discovery. The second phase, involves the creation of the data model to accurately abstract data from the real world into the database. The third phase is the testing of the created data model by developing a prototype system and lastly, the developed prototype is tested with potential users and any necessary changes are made until a level of agreement is reached and the full system can then be implemented. These phases are elaborated further in Sections 3.1, 3.2, 3.3, 3.4 and 3.5.

3.1. User needs assessment and data dictionary

This involves consultations with potential system users in order to determine what they expect from the final product. The users reveal the processes they usually perform and the data they require for these processes. The designer then notes the data present, its suitability for use and determines which of the processes to include in the spatial information system.

3.2. Design of the data model

The selection of the appropriate data model is a critical factor for the success or the failure of the system. For the database of any spatial information system to be completely representative of reality, an accurate data model is required to abstract data from reality into the database. Whereas the first phase does not require any expertise, this stage requires an expert in data model design principles.

The process of designing a data model proceeds in the following levels:

- The conceptual design level; and
- The logical design level.

These levels of data model design and the different approaches used at each level elaborated on.

3.2.1. The conceptual design level

This is the first step in the design of a data model and leads to the development of a conceptual data model. A conceptual data model is a representation of the data to be included in the spatial information system and how the data is connected and related. The conceptual data model is independent of details on how the data model is to be implemented and the software product to be used. At this stage, it is essential for the designer to develop a data dictionary. The data dictionary contains information describing all the entities (to be defined in Section 3.2.1.1) being modelled and the relationships amongst them. This documentation is vital in keeping track of the design progress. This facilitates the discussion with potential users and allows the detection of contradictory definitions. In cases when the designers change during the design process,

with the presence of the data dictionary there will be no need to start afresh. The data dictionary for this research is in Appendix A.

To draft a conceptual data model, a formal approach called the entity-relationship model is used (Healey *et al* 1991, Worboys 1995, Willits 1992).

3.2.1.1. The entity-relationship (E-R) model

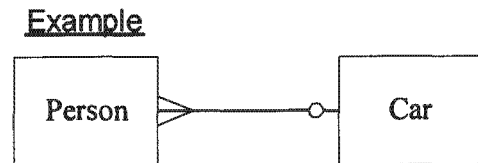
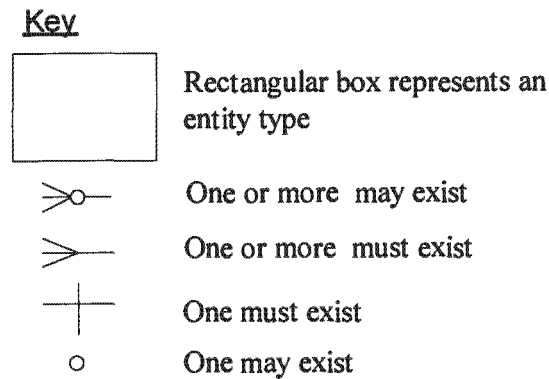
This model views the world as being made up of entities and relationships. An entity is a thing that can be uniquely identified, for example a specific car or a specific person. Entities can be grouped into classes of similar things known as entity types. A relationship is an association among entities or entity types (Chen 1976). An important aspect of a relationship is its cardinality or degree. There are three kinds of relationship degrees, namely:

- The one-to-one relationship;
- The one-to-many relationship; and
- The many-to-many relationship.

The only variations of these arise from how each of the entities will be participating in the relationship. If a relationship is such that each entity must participate in the relationship, then the relationship is obligatory, otherwise it is optional or non-obligatory.

3.2.1.2. The E-R Notation

Since the acceptance of the E-R model, different researchers have come up with their own notations for representing entities and relationships using diagrams. This research will adopt the Crow foot notation, which is illustrated and explained in Figure 3.2 (Connolly *et al* 2002):



The relationship indicated in the example reads as follows:
Forward: A person must own one car.
Backward: A car may be owned by one or more people.

Figure 3.2: The E-R Crow foot notation.

After a conceptual data model has been created in the first level, it is taken to the next level, the logical design level, for further refinement.

3.2.2. The logical design level

This level corresponds to the conversion of the conceptual data model to the logical data model. When the conceptual data model is drafted, it is just a schema of how phenomena are represented in the real world. During the logical design level, the conceptual data model is transformed into a model that can be implemented in a particular software product of choice. Theoretically sound database design principles are required for the transformation of the conceptual data model.

When an attempt is made to implement some of the entities and relationship from the conceptual data model directly into the software, there may be occurrences of redundant data or some relationship that cannot be supported by the software. Principles of database design are then applied to remove the redundancies and properly structure the relationships. This results in a logical model that is ready for implementation in any software of choice.

For designing the logical data model, several approaches can be used, the common ones being:

- The hierarchical model;
- The network model;
- The relational model;
- The object-oriented model; and
- The object-relational model.

The hierarchical model and the network model were amongst the first to be developed. As they both were developed on a tree structure, accessing data from a database created from these models can be difficult. One either has to go through a predetermined relationship or use an algorithm to generate the location for the instant of an entity in the data file (an example is the use of the hashing algorithm in the network data model). Such were the problems of these models that led to the development of the relational model. Although the relational model has become popular, for reasons to be discussed in Section 3.2.2.1 in this Chapter, it is also not without its own drawbacks for some applications. Due to the drawbacks of the relational model, there has been a shift towards the application of either the object-oriented model or the object-relational model in logical data model design (Harrington 2000).

The object-relational model is a hybrid of the object-oriented model and the relational model and it is the model that will be used in developing the logical data model for this research. It is also the model inherent in the software to be used for implementation, which is ESRI ArcInfo®. To be able to fully explain the object-relational model, it is vital to discuss the object-oriented model and the relational model separately and then attempt to derive from these discussions some of the properties inherent in both models that make the object-relational model more superior. Since the relational data model was developed earlier than the object-oriented model, it will be discussed first.

3.2.2.1. The relational model

The relational model captures information from the E-R conceptual data model and represents it as a collection of two-dimensional tables in the database. The road entity is given as an example (see Figure 3.3). Each table is given a name. It is made up of columns or named attribute types and rows or records. Each row contains information relating to one entity. The intersection of each row and column in the table contains an attribute value. The following are the properties of the tables (Codd 1970, Howe 1989, Date 1995):

- The ordering of rows is not important, they can be interchanged.
- The ordering of columns is not important.
- Each row and column intersection must contain one single value.
- Each row in the table must be unique. This requires that in each row, there should be a unique identifier that differentiates that row from the other rows.

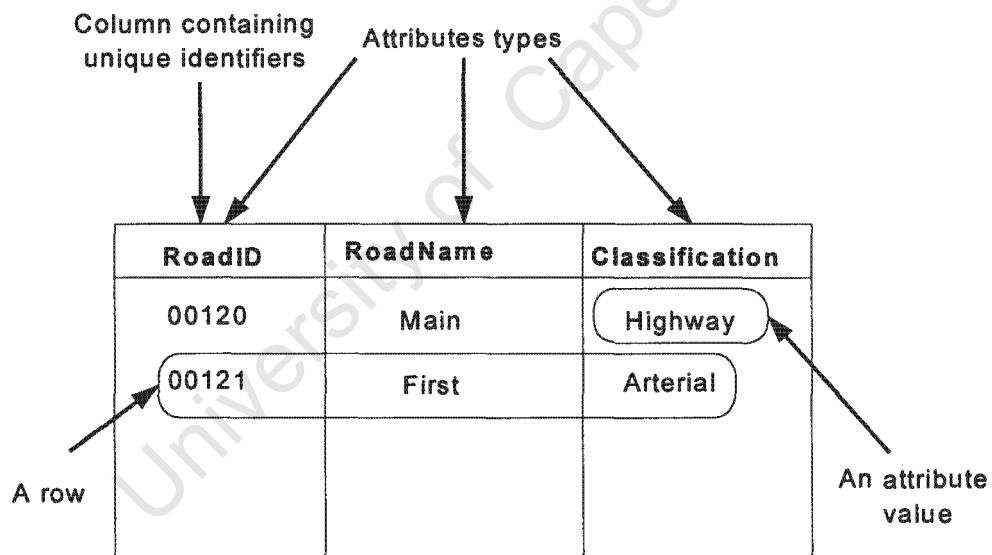


Figure 3.3: The relational model

The relational model uses a well-defined standard data manipulation and data definition language called the structured query language (SQL). This enables users to easily interchange their data between different applications and software products. The other reason why the relational model has become popular is that it is based on a well-developed mathematical theory of relations and first order logic. It also offers tools for

analysing data redundancy and provides the user with a very simplified view of the data in the form of tables (Saake *et al* 1995).

The relational model has been successful in applications that involve tabular data with a simple structure. Examples are applications dealing with bank accounts and personal files, in which the data can be represented as integers and strings. Despite its success with these applications, the relational model has been considered inadequate when it comes to modelling the complex data inherent in spatial information systems and the complex relationships amongst the data. Examples of the complex data include multimedia data like audio, video and images. An attempt to handle some of the complex data leads to the breakdown of spatial objects into smaller parts to enable storage into tables and then regrouping them in response to queries. This slows down data retrieval during query processing.

Another drawback of the relational model is that it relies on the idea that they can only be one correct value for each piece of data at any one time, whereas in spatial information systems, they can be different users working on concurrent versions of the same database, as illustrated in Figure 3.4 (Egenhofer 1996, Worboys 1996, Cooper 1997).

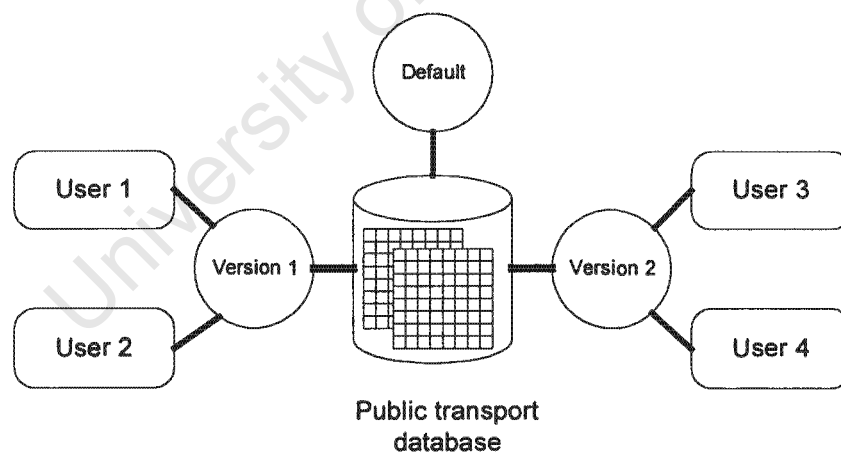


Figure 3.4: A database with multiple versions.

Spatial information systems involve the integration of data from various sources into one system, using geographic location. This requires models that enable the

representation of the same data at different levels of detail while maintaining the possibility of performing several tasks.

Due to the limitations of relational models explained, designers have turned to the object-oriented model, which is based on the object-oriented approach commonly used in programming (Egenhofer 1992, Clodoveu 1994, Fletcher 1996, Trépanier *et al* 2001).

3.2.2.2. The object-oriented model

The object-oriented approach has been in use in programming languages since 1966. Due to some of the advantages offered by this approach in programming, researchers moved for the application of its concepts in data model design. The result is the application of the object-oriented model in data model design (Hughes 1991). The rest of the section discusses the important concepts of the object-oriented approach that define the object-oriented model. The concepts of the object-oriented model to be discussed highlight some relationships that are inherent between entities in the real world, which the relational model fails to capture (Harrington 2000).

Before discussing the concepts of the object-oriented model, it is essential to provide a distinction between entities and objects. In the object-oriented model, all the entities in the conceptual data model are treated as objects. The difference between entities and objects is that an entity is defined by attributes only, whereas an object, besides having attributes, has a set of operations that it can perform or that can be performed by other objects on it. These define its behaviour. Taking the road object as an example, operations it may have include the following:

- Constructor operations: operations for creating a new road or deleting an existing road.
- Accessor operations: operations that can perform calculations for the road, for example calculating its length.

Objects with the same behaviour are organised into one class. Therefore, each object is described as an instance of a class (Worboys 1994). An example of such an object is illustrated in Figure 3.5.

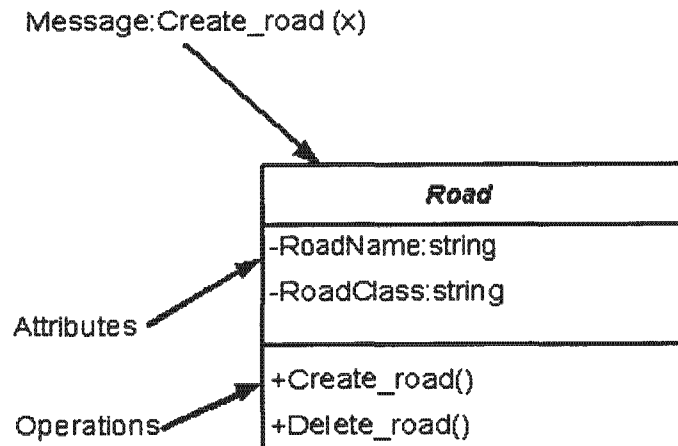


Figure 3.5: A road object with attributes and operations it can perform

Objects communicate with each other using messages (Hawryszkiewicz 1994 and Milne *et al* 1993). In Figure 3.5, an object sends a message called 'Create_road x' to the road object. The message is transmitted and activates a process in the road object. When the road object receives this message, it has an operation that performs this task. It also has an operation for deleting a road from the attributes.

Object identity

Each object is assigned a unique identifier (ID) by the software when the object is created. The ID cannot be changed and is only abandoned when the object is deleted from the database. This ID, unlike in the relational model, is independent of the attribute values. Therefore, it is unnecessary to provide variables for the purposes of identifying an object.

Encapsulation

Encapsulation enables objects to hide the methods they use to implement their operations. An object has an interface part and an implementation part. The user can ask the object to perform tasks through the interface and can only see the result after the task is implemented, and not the operation itself used to accomplish the task, which is part of the implementation part. Once the object's interfaces are defined, the object can perform only the operations specified. The implementation part can be changed without changing any of the programs in the interface (Bancilhon 1996).

Inheritance

Inheritance allows a new class to be created using the data and operations declared for another class. It acts in two ways, through generalisation and specialisation, which are illustrated in Figure 3.6. Generalisation groups several objects into a more general superclass. Properties common to a superclass and its subclasses are defined only once, at the superclass and are inherited by the subclasses. But properties defined for the subclass are not compatible with the superclass. In Figure 3.6, the super class is 'vehicle' and the subclasses are 'car' and 'bus'. Car and bus are generalising into a vehicle (Bancilhon 1988 and Shekhar 1996).

Specialisation is differentiating types according to specific roles, for example the vehicle object specialises into a car and a bus. When the model illustrated in Figure 3.6 is implemented, the car and bus will also contain the attributes of vehicle, which are the maximum weight and the registration number, in addition to their own attributes.

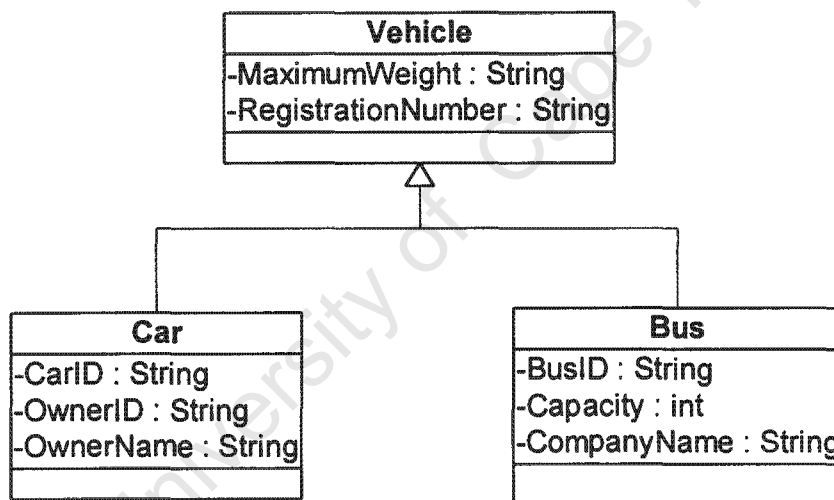


Figure 3.6: The object-oriented concept of inheritance

Aggregation

Through aggregation, an object is created, which is made up of component objects. The aggregate object is treated as one unit in many operations although it is made up of smaller objects (Frank 1996). An example is given in Figure 3.7, where a transport network is made up of roads and stops. The diamond is the UML diagramming

notation¹⁰ for representing aggregation, * represents many, for example many stops and roads can make up a network.

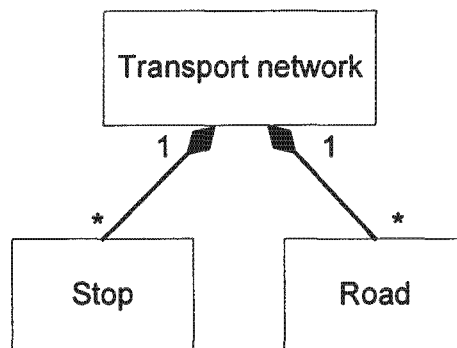


Figure 3.7: The concept of aggregation.

Association

An association represents the relationships between objects. An association has multiplicities, which are an indication of the number of objects that can participate in a relationship. In Figure 3.8, the UML Notation indicates the relationship multiplicities. The sign '*' represents 'many' and '0..1' represents 'one'.



The association indicated by the example reads:

Forward: A person must own one cars.

Backwards: A car may be owned by one or more people

Figure 3.8: The concept of association.

Polymorphism

This allows the same operation to be implemented using different methods in different classes. For example the operation 'Calculate_area' has different implementations for the rectangle, circle or triangle classes.

¹⁰ The UML Notation is one of the notations used in representing objects and other concepts of the object-oriented model (it is comparable to the E-R notation used with the relational model).

From the discussion provided on the various concepts of the object-oriented model, it can be deduced that the object-oriented model offers a more representative abstraction of data than the other models. However, it does have its disadvantages. One drawback of the object-oriented model is poor performance. This is due to the fact that accessing the data enclosed in objects, which have a complex structure, through methods built on a rich set of operators poses problems of query optimisation¹¹. Encapsulation states that the data should be hidden from users whilst the query needs to see the internal structure of the objects. Another drawback is that it is not suitable for ad hoc querying like the relational model. It is also unable to support large-scale database systems. Given these shortcomings, the object-relational model is considered as a superior alternative (Devarakonda 2001, Bancilhon 1988).

3.2.2.3. The object-relational model

The object-relational model is a hybrid model. It is primarily relational but the object aspect of the model emerges from that fact that it stores objects, as opposed to entities in tables. These objects are implemented subject to the same rules that apply to the relational model. It was designed to capture the benefits of both the relational and object-oriented models highlighted in the preceding discussions. It aims to enhance the capabilities of the relational model. The object-relational model supports complex data types and even provides an interface for the user to define new data type. It also supports the complex relationships explained for the object-oriented model in Section 3.2.2.2 (Franklin 1996).

One advantage of the object-relational model is that the resulting database has substantial scalability¹². The objects-relational model has the ability to query and handle complex applications. With the object-relational model data can be accessed faster and queries can be performed using the standard SQL language. The problem of query optimisation faced with the object-oriented model is solved in the object-relational

¹¹ Query optimisation is the process of analysing a query to determine what resources it requires and how to execute the query with the least possible cost.

¹² Scalability is how performance changes when the database size increases.

because it uses indices and advanced query optimisation techniques of the relational model (Harrington 2000).

This is the model to be used in this research and is also inherent in the implementation software, ArcInfo. It is further discussed in Chapter Four, along with the implementation details.

3.2.3. Development of a prototype

There are various ways of doing this. In this research the prototyping approach is used. In this approach, a working prototype model for the system is designed, with limited functions (Ince 1995). The database is populated with a sample of the data to be included in the system. In most cases, it is necessary to design a user-friendly graphic user interface (Galitz 1989). It is also during this stage that matters regarding how information will be retrieved from the database, how the database will be updated and the kind of processes that can be performed by the system are highlighted.

3.2.4. Testing the designed prototype

After development of the prototype model in a software product, it is essential to test it on the potential users of the system in order to get their responses. This is the purpose of the fourth phase. It is these potential users who decide on whether the system is suitable for their use or not. If not, the designers have to make the necessary changes, until some level of agreement is reached with the user.

3.2.5. Implementation of the system

After the users agree to the developed prototype system, all the data is added into the database, all functions of the systems are installed and the designed prototype becomes a complete system that is implemented for the user to perform queries and execute other predefined processes.

3.2.6. Summary

This chapter discussed the stages involved in designing a spatial information system and the approaches used at each stage were compared and contrasted. Choices were made on

which approaches to use for this research based on the presented arguments. The selected approaches are used in explaining the development of the data model for this research in Chapter Four.

University of Cape Town

Chapter Four

Design and implementation of the public transport information management data model

4. Introduction

The previous chapter elaborated on the phases of spatial information system and provided insight into the different approaches used in each phase, with the main being on the data model design phase. Whereas the last chapter was theoretical, this chapter provides a detailed discussion on the conceptual data model designed in this research and the transition from a conceptual data model to a logical data model. The details of implementation of the data model in the software of choice and the development of the prototype are also provided.

4.1. The public transport information management conceptual data model

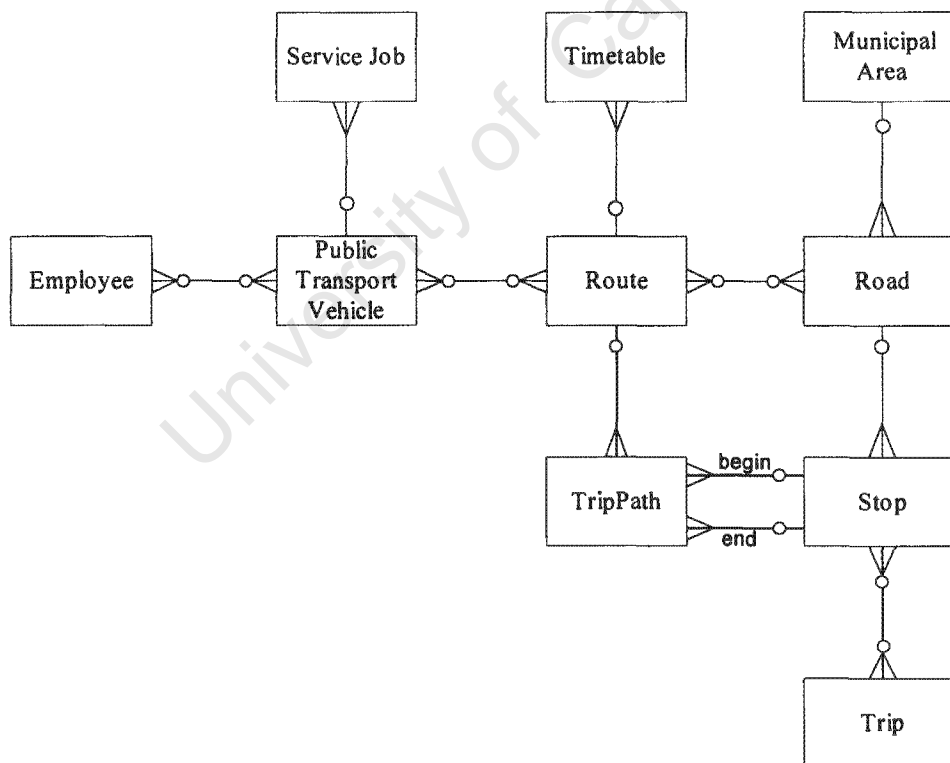


Figure 4.1: The conceptual data model.

Figure 4.1 shows the conceptual data model that was designed in this research for public transport data management, all the entities involved and how they are related. The rest of this section explains each of the entities presented in the conceptual data model.

The *municipal area* represents the area in which a road is located. A town is divided into different municipal areas. In each area, the municipality is responsible for the supply and maintenance of infrastructure. A *road* represents the network that is used daily by different modes of transport. A road must be located in one municipal area but one municipal area may have one or more roads in its area.

The *route* is a physical feature representing a path taken by a public transport vehicle travelling along the transport network. A route may use one or more roads and a road may have one or more routes using it.

The *timetable* represents any information on the daily times and services available for each mode of public transport. A route may have one or more timetables but a timetable must be for one particular route.

Public transport vehicle represents all the different modes of public transport, that is buses, trains and minibus taxis. *Service job* is a record of any maintenance or repair work performed on a public transport vehicle. A public transport vehicle may have one or more service jobs but a service job must be for only one public transport vehicle. The *employee* object contains information on the public transport vehicle drivers. A driver may drive one or more public transport vehicles and a public transport vehicle may be driven by more than one driver.

The *trip* and *trip path* entities are included in the data model to cater for the inclusion of ride check survey data into the system. A trip represents the journey taken by a public transport vehicle from an origin stop to a destination stop. A trip path represents the section of a route. It is the path from one stop to the next stop. A trip path must begin at one stop and end at another stop but a stop may have many trip paths passing through it. A route may have many trip paths but one trip path must be for one route.

Stop represents a place where the public transport vehicle stops to pick up and drop off passengers during any particular trip. Stops include bus stops, bus termini¹³, train stations, minibus taxi ranks and trip stops. A trip stop, in the case of representing the ride check survey data, represents a point where the bus stopped to drop off or pick up passengers but which is not a designated stop. A road may have one or more stops, and a particular stop can only be located along one road.

As has been highlighted in the previous chapter, the conceptual data model has to be transformed into a logical data model for implementation. Section 4.2 below discusses these transformations in relation to the conceptual data model explained above and presents the logical data model.

4.2. The public transport information management logical data model

As was stated in Chapter Three, the object-relational model is to be used to develop the logical data model. All the entities discussed for the conceptual data model at the beginning of this chapter are treated as objects. Despite the fact that the entities are treated as objects and have custom behaviour, they are subject to the design rules of the relational model. After applying these rules, a logical data model is produced that is well structured and has no redundant data. This structuring of data to remove redundancy is called normalisation.

The route-timetable and the road-route relationships are used as examples to show the transformation from the conceptual data model to a logical data model.

The route- timetable relationship

Table 4.1 illustrates the structure of the route-timetable relationship from the conceptual data model.

¹³ A bus terminus is a collection of two or more bus stops.

Table 4.1: The route-timetable relationship table

Timetable Name	Timetable ID	RouteName	RouteID
B-CT1	T1	Blaauwberg to Cape Town	RT1
B-CT2	T2	Blaauwberg to Cape Town	RT1
S-CT1	T3	Sea Point to Cape Town	RT2
S-CT2	T4	Sea Point to Cape Town	RT2
S-CT2	T5	Sea Point to Cape Town	RT2

From Table 4.1, the one-to-many relationship between route and timetable leads to the existence of some redundant data in the database. For example, the route names 'Blaauwberg to Cape Town' and 'Sea Point to Cape Town' have been repeated. This increases the size of the database. Another problem is that each time a new timetable is added into the database for one of these routes, the route name has to be retyped. If there are any spelling mistakes, then some of the information is not retrieved when queries are performed. To structure this relationship properly using the relational model, two tables are created for route and timetable, and the RouteID is posted into the timetable table (see Table 4.2). The same is done for the other one-to-many relationships in the conceptual data model.

Table 4.2: The normalised route-timetable relationship tables

Timetable Name	Timetable ID	RouteID
B-CT1	T1	RT1
B-CT2	T2	RT1
S-CT1	T3	RT2
S-CT2	T4	RT2
S-CT2	T5	RT2

RouteName	RouteID
Blaauwberg to Cape Town	RT1
Sea Point to Cape Town	RT2

The route-road relationship

Table 4.3 illustrates the structure of the route-road relationship from the conceptual data model.

Table 4.3: The route-road relationship table

RouteName	RouteID	RoadName	RoadID
Blaauwberg to Cape Town	RT1	Blaauwberg Road	RD1
Blaauwberg to Cape Town	RT1	Koeberg Road	RD2
Atlantis to Cape Town	RT2	Blaauwberg Road	RD1
Atlantis to Cape Town	RT2	Koeberg Road	RD2

If the relationship was to be represented as illustrated in Table 4.3, there would be occurrences of redundant data in the database. For one or more routes sharing the same roads, the road name is repeatedly entered. Also, for roads sharing similar routes, the route name is repeatedly entered. The same problems are faced in data updating as explained for the route-timetable relationship.

Unlike the one-to-many relationship, which can be structured by posting the RouteID into the Timetable table, many-to-many relationships can only be structured well by constructing a third table to represent the relationship (see Figure 4.2.). A combination of the RouteID and RoadID uniquely identifies a row and this type of identifier is called a composite identifier.

RouteName	RoutelD
Blaauwberg to Cape Town	RT1
Atlantis to Cape Town	RT2

RoadName	RoadID
Blaauwberg Road	RD1
Koeberg Road	RD2

RoutelD	RoadID
RT1	RD1
RT1	RD2
RT2	RD1
RT2	RD2

} Relationship table

Figure 4.2: The normalised route-road relationship tables

After structuring the relationships as explained, the logical data model is created. This is represented in Figure 4.3. The logical data model shows posted identifiers from other tables, for entities participating in relationships. All unique and composite identifiers are shown underlined for each relationship.

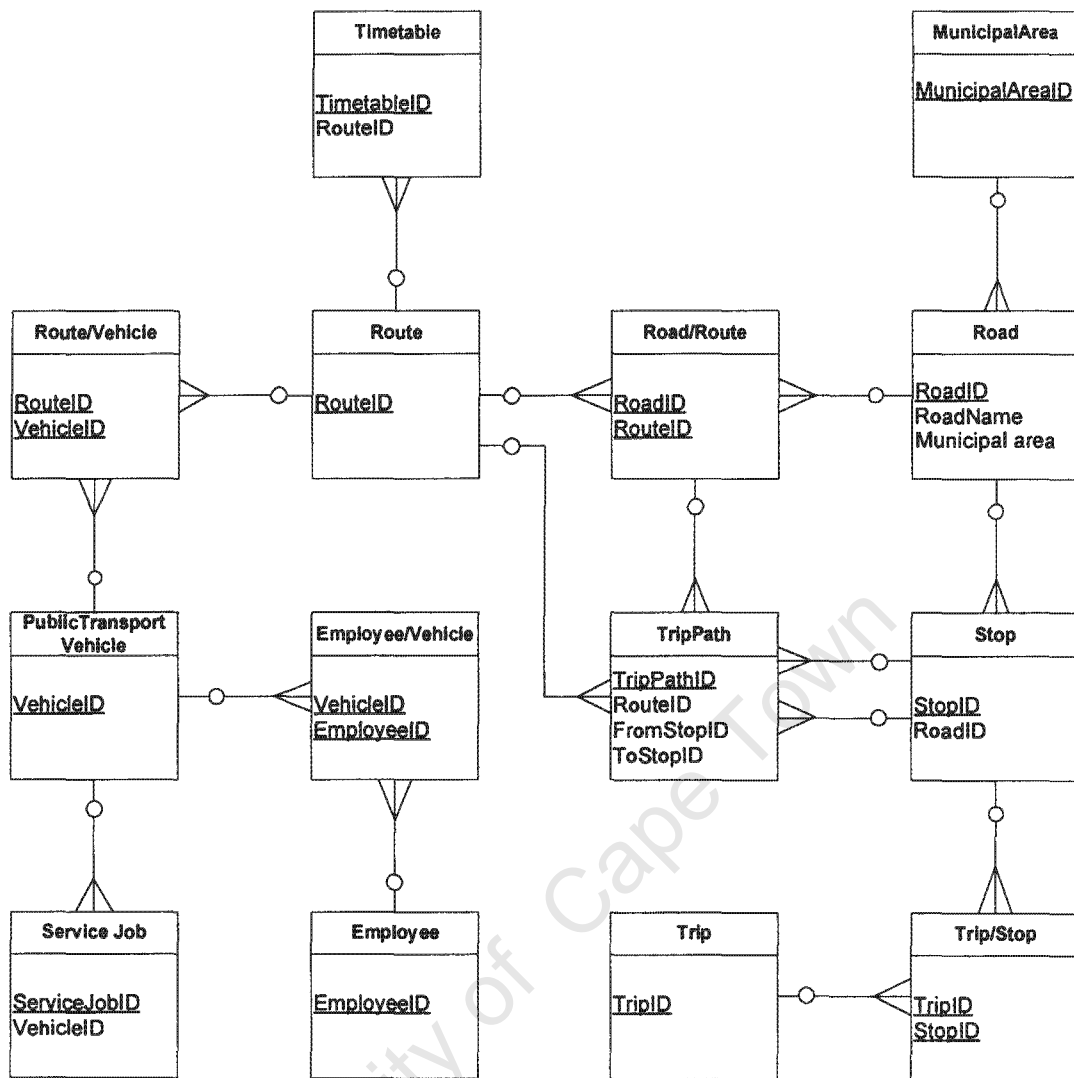


Figure 4.3: The logical data model

The data model presented in Figure 4.3 is ready for implementation. Prior to the discussion of any implementation details, it is vital to discuss some components of the software, how the object-relational model is supported in the software and how each of these entities is to be represented, both in the database and spatially. Although the data model has been general to all public transport modes, for implementation, the mode of transport used are buses.

4.3. Implementation of the data model in ArcInfo

The version of ArcInfo used is 8.2, which is part of the ArcGIS® software package created by ESRI Inc. ArcInfo was selected because it was the only software available that supports the object-relational model. Figure 4.4 illustrates the structure of the ArcGIS software.

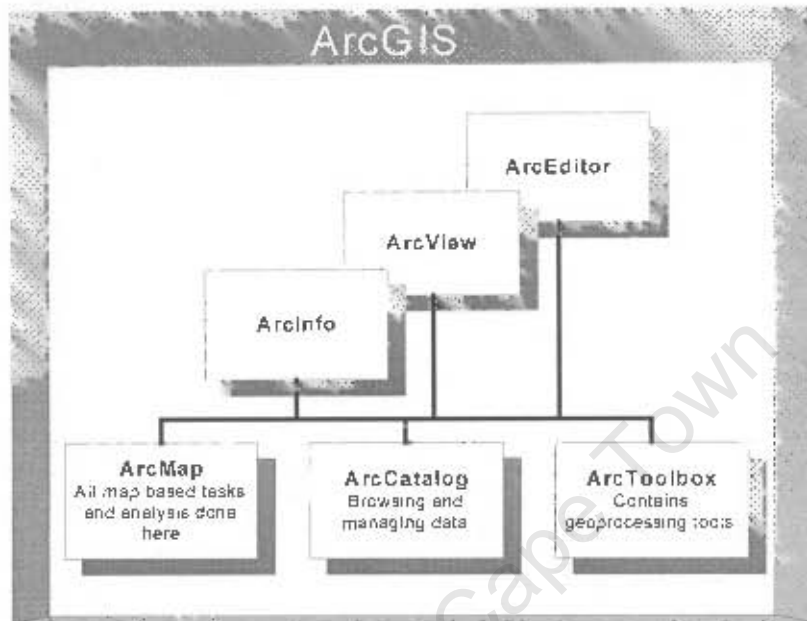


Figure 4.4: The structure of the ArcGIS software package

In the ArcGIS software, the user selects whether to work in ArcInfo, ArcView or ArcEditor. ArcInfo was selected because it has options for creating and editing geodatabases, creating networks, advanced geoprocessing capabilities and data conversion using ArcInfo Workstation. The desktop applications for each of them are ArcMap, ArcCatalog and ArcToolbox.

There are several factors considered in implementing the data model, ranging from the creation of the database, the representation of spatial features and database population in the software. These are discussed in the following sections.

4.3.1. Object-relational modelling in ArcInfo

ArcInfo contains a geodatabase data model, which is object-relational. One of the most important concepts of the object-relational model that is mainly used in the geodatabase is inheritance, which has been discussed in Chapter Three. In ArcInfo, there are some predefined objects that perform specific operations. Through inheritance, the designer selects custom objects in ArcInfo with properties similar to those of the objects created in the logical data model. All the created objects can then inherit their properties from the custom features already available. This procedure can be performed in ArcCatalog, or using the Computer Aided Software Engineering (CASE) Tools available in the Unified Modelling Language (UML) (Zeiler 1999).

In this research, CASE Tools using UML in Microsoft Visio Enterprise 2000® were used. The selection of Microsoft Visio Enterprise 2000 was based on the fact that it is one of the software products containing UML that is supported by ArcGIS. In UML, a schema is created; the one illustrated in Figure 4.5 is an example. This schema is based on the ArcGIS Transportation Model, which was developed by ESRI and is distributed on the World Wide Web.

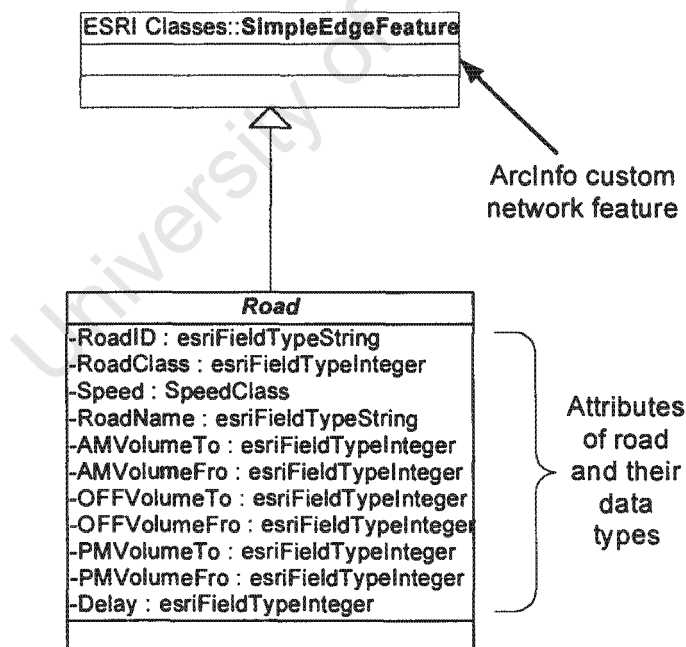


Figure 4.5: The road object and inheritance

In this schema, the ArcInfo custom objects selected are illustrated along with the designed objects and the relationships indicated. For example, in Figure 4.5, the custom ArcInfo object is the simple edge feature. It is used to model linear features that represent network features like roads, railway lines and rivers. The simple edge feature has custom behaviour that distinguishes it from other linear features. This enables network lines to be differentiated from other lines for example, straight lines representing the edges of a building. The road, from the logical data model, therefore inherits the properties of the simple edge feature in ArcInfo. The rest of the schema, representing the other objects present in the logical data model has been placed in Appendix B.

After the schema is created using UML, it is exported to the Microsoft Repository. The created Microsoft Repository is then imported into ArcCatalog, where a personal geodatabase (the one called Prototype and is shown highlighted on the left hand side of the box in Figure 4.6) is generated.

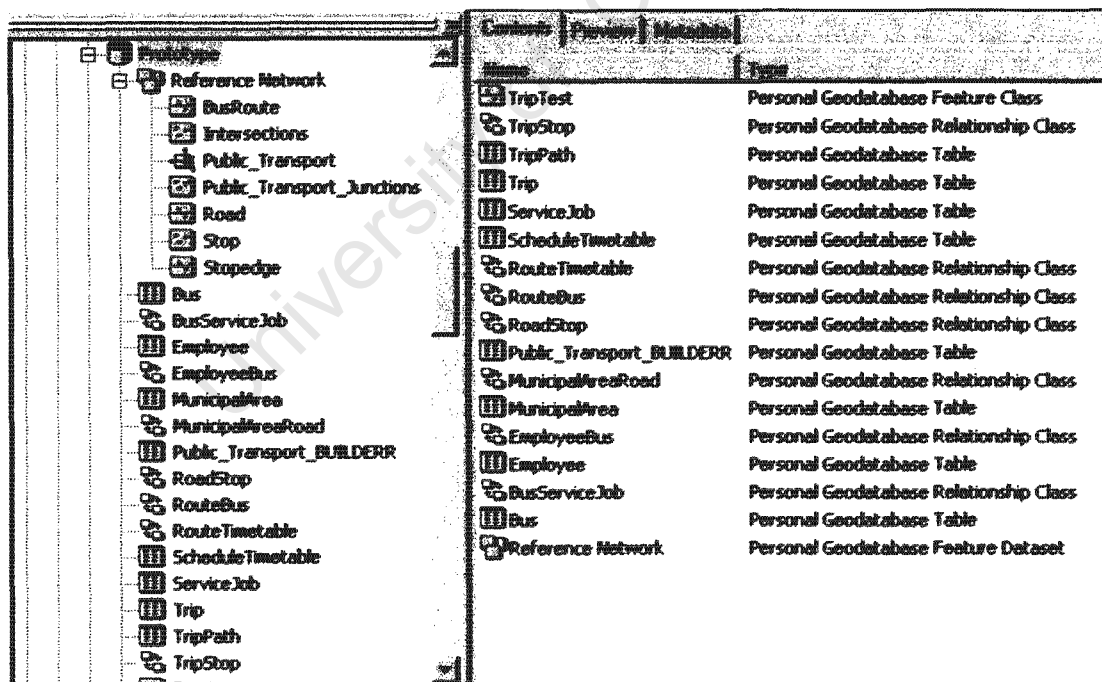


Figure 4.6: The created personal geodatabase

To the right hand side, in Figure 4.6, all objects present in the logical data model are created either as features or tables. After the geodatabase is created in ArcCatalog, projection parameters are set, the relationships are created and the tables are then

populated with data. Table 4.4 shows the data sets used to populate the geodatabase, where the data was acquired from, and the format the data was in during acquisition.

Table 4.4: The data sets used

Data set	Format	Type	Department where acquired from
Road centrelines	Digital	ESRI ArcView shapefiles	Cape Metropolitan Council
Bus stops and bus termini	Digital	ArcView shapefiles	Cape Metropolitan Council
Traffic count data	Digital	Microsoft Excel spreadsheet	Cape Metropolitan Council
Ride check survey data	Digital	Microsoft Excel spreadsheet	Cape Metropolitan Council

The following sections discuss how each of the spatial data features and the non-spatial data are represented in the software.

4.3.2. Representation of spatial objects

Road

The road is modelled as a network feature. In the geodatabase model, a network is made up of edges and junctions. The edges correspond to road sections and the junctions to road intersections (see Figure 4.7).

The representation of the network is a dual one, including the geometric network and the logical network. The geometric network is the view of the network as being made up of connected elements such as roads, stops, railway lines and stations. This is the network the user creates in the geodatabase.

Behind the scenes is a logical network, which is created by the system for every geometric network that is created in the geodatabase. The logical network stores information on the connectivity of the elements in the geometric network. The logical

network is a graph. Each edge has a weight associated with it that represents the cost incurred when traversing along it. This weight could, for instance be the volume of traffic along that edge or time taken to travel along that edge. This consideration of the network as a graph made up of weighted edges enables the performance of network analysis like the shortest path analysis, which is one of the most important analysis available in spatial information systems and applicable to public transport (Laurini *et al* 1996, Miller *et al* 1999, Waters 1999).

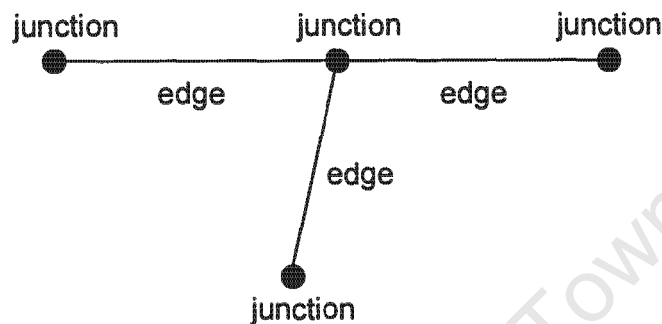


Figure 4.7: A network with three edges and four junctions

Route

When a linear feature is created in ArcInfo, it is made up of nodes and arcs, popularly known as the node-arc model. The nodes mark the beginning and end points of that line, thus a line; must start and end at a node. Attributes representing the linear feature are placed either in the node table or the arc table. This representation is ideal when attributes are constant between any two nodes making up an arc. This model becomes restrictive when dealing with features that have varying attributes along an arc, for example the number of passengers travelling along a section of a route- as will be illustrated in the example in Figure 4.8 and Figure 4.9. If, for example, some attribute value changes between the two end nodes, an extra node has to be placed at that point and this splits the arc into two parts. This splitting of arcs and adding of nodes increases the size of the database.

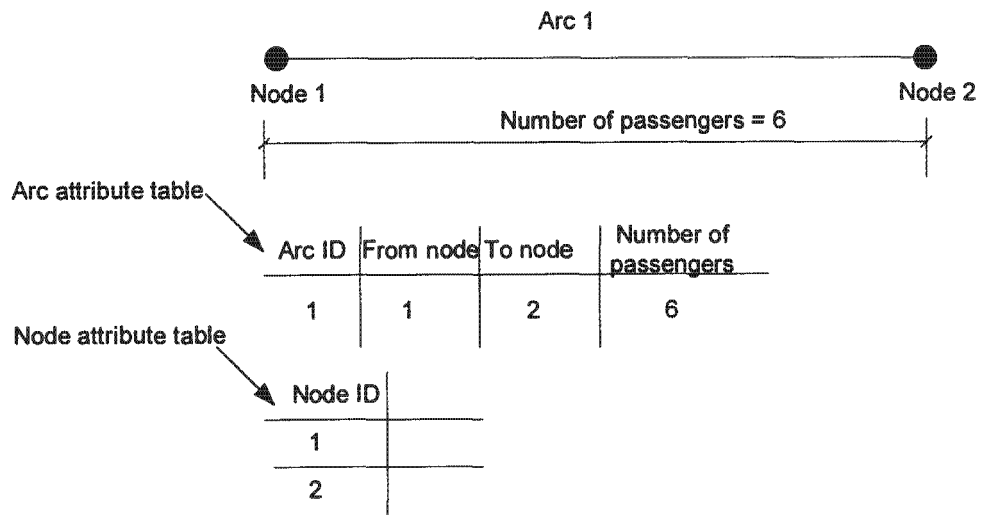


Figure 4.8: Representation of route attributes using the node-arc model

From Figure 4.8, the node-arc model is used to represent the number of passengers travelling along a route. It also illustrates how the arc attribute and node attributes tables are set out to represent this information. It might be required to present this information for different times of day or different days of the week and the statistics would probably vary. Instead of having six passengers travelling along the same section of the route, the arrangement changes to that illustrated in Figure 4.9.

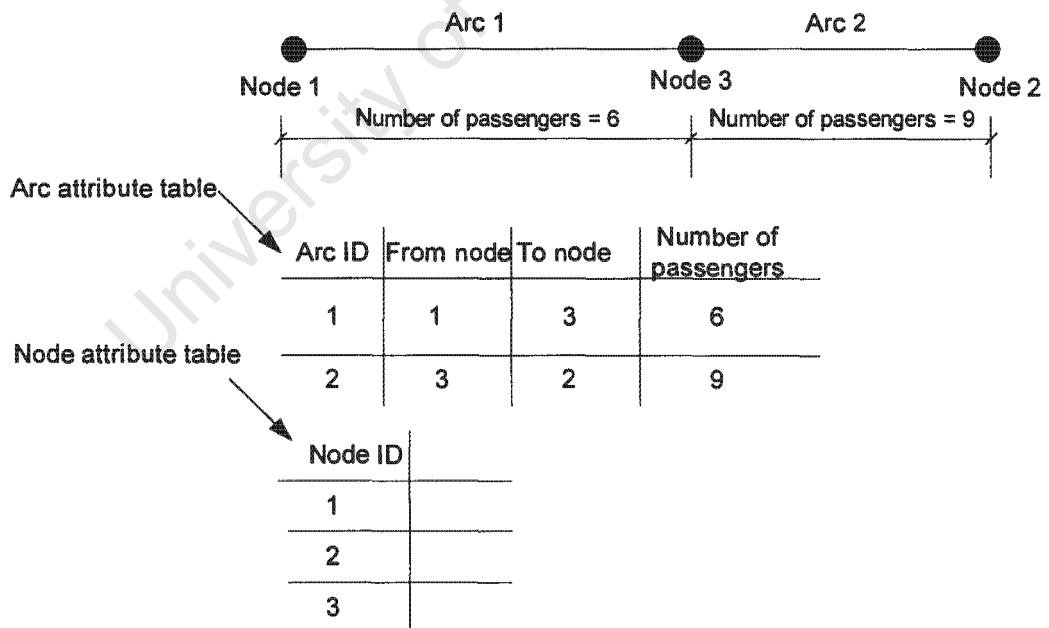


Figure 4.9: Representation of route attributes using the node-arc model

All the other information related to the route, for example stops locations, are modelled as events using the measures from the measure system formed. In this research, the trip path object in the data model is modelled as an event illustrating the approximate number of passengers who were travelling along a particular section of the route during the ride check survey, from one stop to the next. The hatched line in Figure 4.10 is representing an example of the trip path event. The thicker the hatched line, the more the passengers there are along that section of the route. The following are examples of the type of information that can be derived from Figure 4.10:

- From stop 1 to stop 2, there were five people in the bus.
- From stop 2 to stop 3, there were ten people in the bus on that particular trip.

Stop

The stops are represented as a separate layer of point features with x and y co-ordinates. As explained in Section 4.1, a stop can either be a bus stop, a bus station, or an undesignated place where the bus stopped to drop off and pick up passengers during the ride check survey. These three variations of stop are represented using subtypes. The three subtypes inherit the attributes and properties of stop (see Figure 4.11). The subtypes can be represented on the map using different symbols (see Figure 5.7).

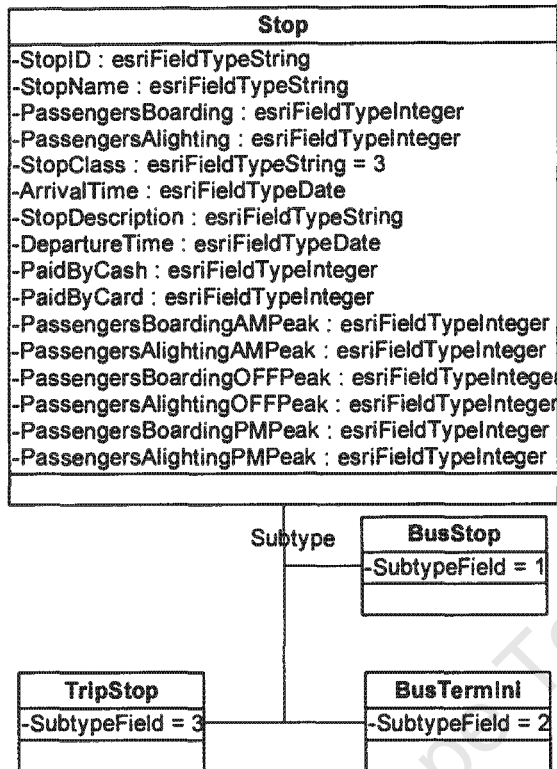


Figure 4.11: Representation of stops using subtypes

4.3.3. Representation of non-spatial objects

The other objects of the data model with no spatial representation are modelled as tables. Tables were created in the geodatabase for employee, service job, timetable, trip path and municipal area. The relationships between the objects are modelled as relationship classes.

4.3.4. Integrity of data in the database

Maintaining the accuracy of the database after updates are made is a very important aspect of any spatial information system (Miller *et al* 1996). The geodatabase data model enables the maintenance of accurate attribute data in the database by allowing constraints to be set for the attributes through the use of attribute domains. Attribute domains prevent the presence of invalid data in the attribute tables. These are specified when the personal geodatabase is constructed. There are two types of attribute domains:

verification check has to be performed. All the values that are outside the domain will be highlighted and therefore will have to be edited.

The attribute domains specified in the implementation of the geodatabase for this research are as follows:

- The road class attribute type has the following coded value domains:
 - Freeway
 - Main Road
 - Secondary Road
 - Other

The road speed attribute type has a range domain. The valid numeric values are any number between the minimum value, which is 0 and the maximum value, which is 120.

Another way of ensuring the presence of accurate data in the database is by allowing only authorised personnel to update or delete data from the database (Connolly *et al* 2002). In this prototype, editing can only be performed in ArcMap. When a user attempts to edit the data, he or she is prompted for a user name and a password through the dialog box. If the password and user name are incorrect, no editing can be performed. A password is also required to customise the prototype.

4.4. Customisation and developing the graphical user interface

One of the important aspects in designing a spatial information system, which is rarely addressed in most systems, is how the users will interact with system, often called human-computer interaction (HCI). Most systems are developed with all the functions but not taking the user into account. These systems quickly lose popularity and this leads to losses, in time and financial resources, trying to improve the systems after they have already been implemented (Inec 1995).

The users interact with the system through a user interface. A good interface should be user friendly, so that the user feels happy and confident with the software at hand. The interface should be robust and should not fail when the user enters incorrect data. All the

information required by the user should be output in an easy to read format (Hawryszkiewicz 1994 and Shepperd 1995).

In this research, although the whole system database was created in ArcInfo, it was decided to create a stand-alone application, with an easy to use graphic user interface using Microsoft Visual Basic 6.0 and MapObjects Version 2.0. With the geodatabase still residing in ArcInfo, a connection was made from Visual Basic to the geodatabase using the data environment in Visual Basic. Relevant information is then extracted through the connection by writing SQL statements. This information is then displayed on forms when the user selects an option that requires this information.

The expert user can perform the more complex analysis, for example Network Analysis and editing in ArcMap. The layout of the system is provided in the Figure 4.13.

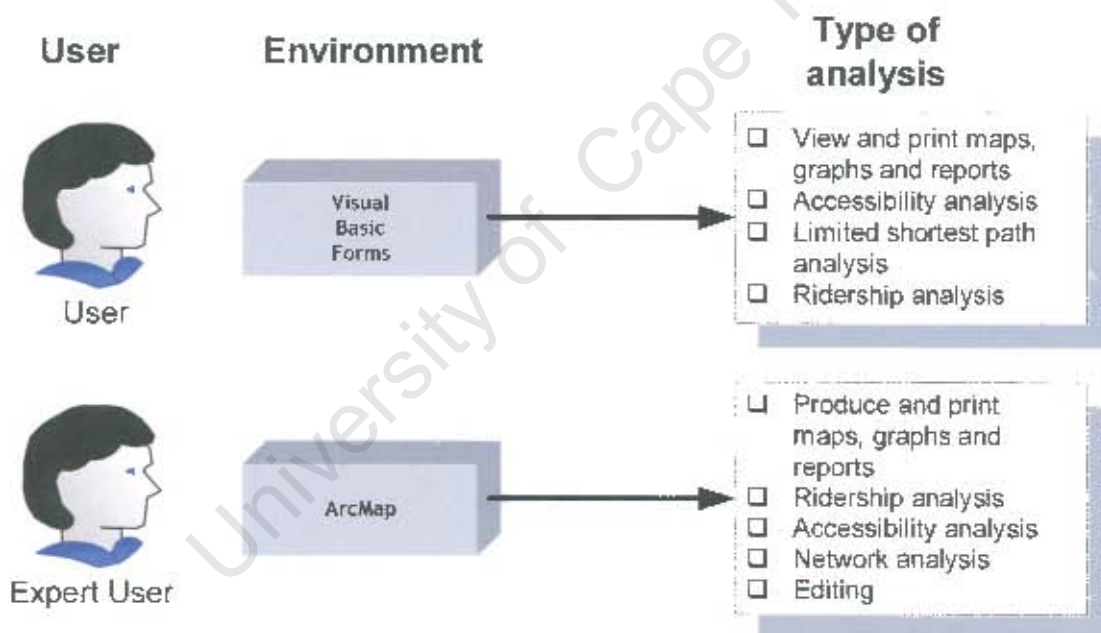


Figure 4.13: Layout of the spatial information system.

The system is also structured such that most of the information required by the user is output in graphical form, either as graphs, reports or map layouts. This makes the information easier to interpret.

4.5. Summary

In this chapter, the design of the public transport data management conceptual and logical data models, the implementation of the data model in ArcInfo, the development of the prototype and the data acquired and used for the prototype have been discussed. The next chapter examines how the system works, what the kind of information can be retrieved from it and the functions it can perform.

University of Cape Town

Chapter Five

System Functions

5. Introduction

This chapter presents sample analysis that can be performed by the prototype system and the type of information that can be obtained from it. The rest of the analyses are described in Appendices C and D.

5.1. Using the system

On opening the program, the user can select any of the following analysis:

- Passenger analysis;
- Spatial queries;
- Shortest path analysis; and
- Ride check survey analysis.

It is important to state that each of the analysis highlighted above can be performed both in the Visual Basic application and in ArcMap. The main difference is that in the Visual Basic application, everything is predefined and ready for printing whereas in ArcMap, the user has the option of selecting a variety of symbols and colours. The main queries are discussed here but the rest of the functions are defined in the manual in Appendix D. Each of the analysis is explained separately. The type of information that can be obtained after each analysis and the format the information will be received in is also discussed, using illustrative diagrams. For the passenger analysis and accessibility analysis, the presented results are from the Visual Basic application and for ride check analysis and shortest path analysis, there are from ArcMap.

5.2. Passenger analysis

Passenger analysis is performed when it is required to display and output information on the number of passenger using a particular bus route or getting on and off at each stop. The user can select to view the amount of passengers:

- Travelling along one specific route for the different times of day¹⁴;
- On different times of day for all routes; and
- Boarding and alighting per stop for the different times of day.

Figure 5.1 illustrates a map showing the number of passengers who boarded and alighted at each stop during the AM Peak along the Atlantis-Cape Town bus route.

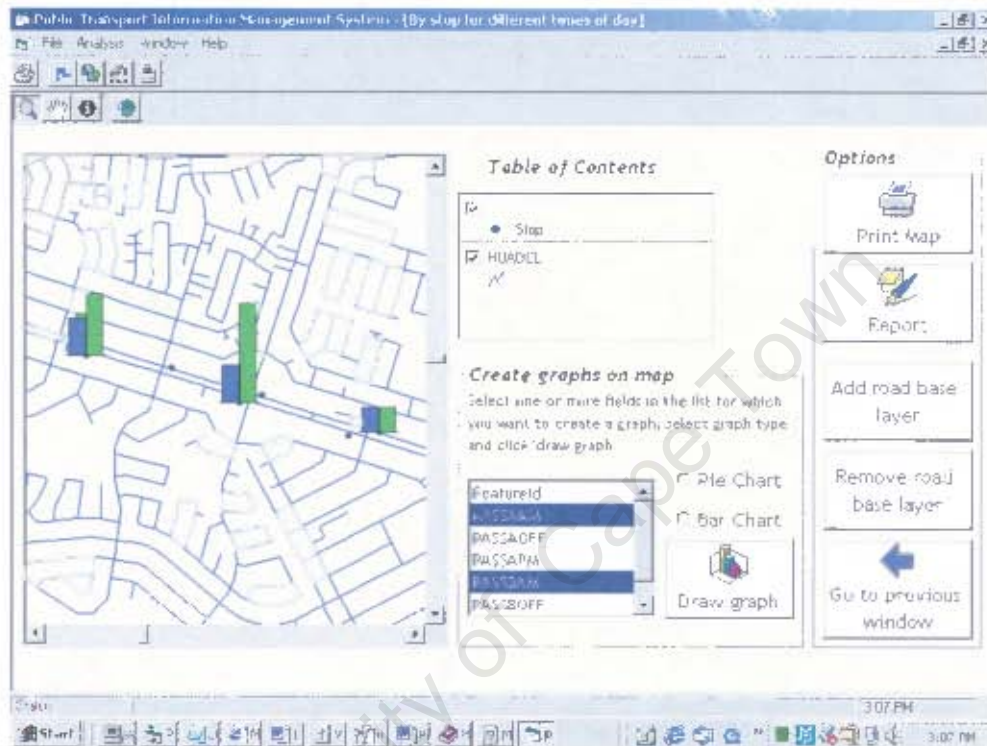


Figure 5.1: Passengers boarding and alighting at each stop.

5.3. Accessibility analysis

This type of analysis can be performed after selecting the 'spatial queries' menu item. An example of this type of analysis is when it is required to assess the approximate number of people living within a distance of a stop, for example, 100 meters. The census data polygon layer is added to the map and the selection is done based on this layer. After the query is done, the population tracts within 100 meters of the specified

¹⁴ There are three different times of the day, the AM Peak, the PM Peak or the OFF Peak. AM Peak is the morning peak period, when a lot of people are going to work, from 6:30 am to 10:30 am. OFF Peak is from 10:30am to about 3:30 pm and PM Peak is the late afternoon period when most people are returning from work, from 3:30 pm to 6:30 pm.

stop (the one highlighted in yellow in Figure 5.2) are selected and converted to a shapefile (see Figure 5.2). They are displayed on the map and the population information gathered from their attributes.

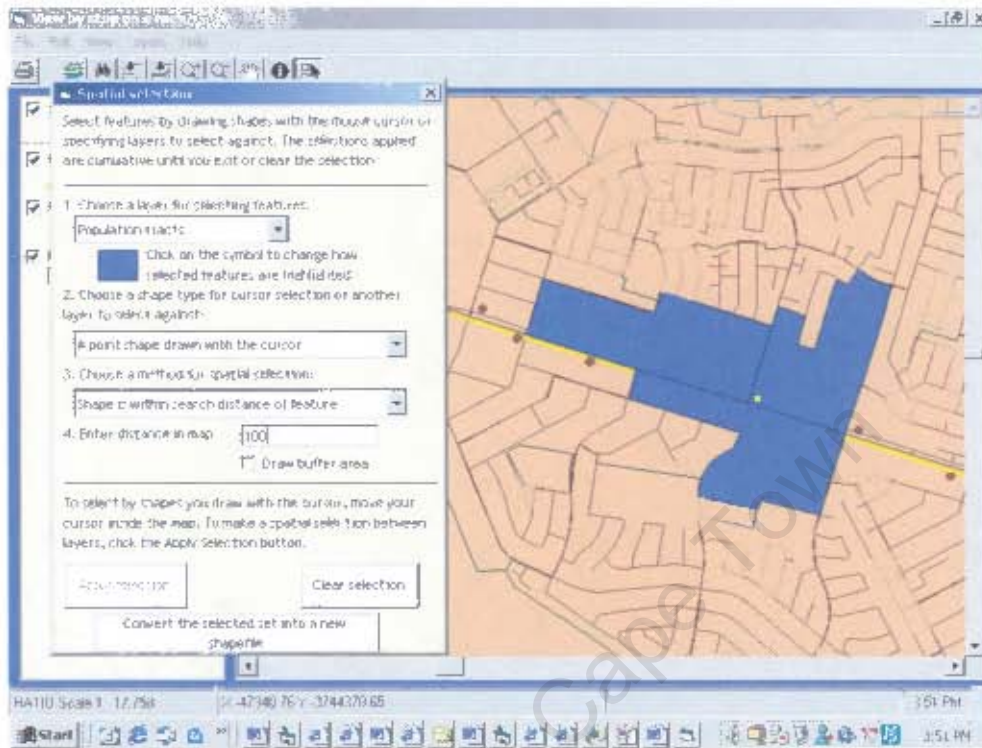


Figure 5.2: Population tracts within 100 metres of the stop

From the population tracts attributes, statistics on the number of people can be derived. For example, for the query executed in Figure 5.2 the attributes of the three population tracts selected are shown in Figure 5.3.

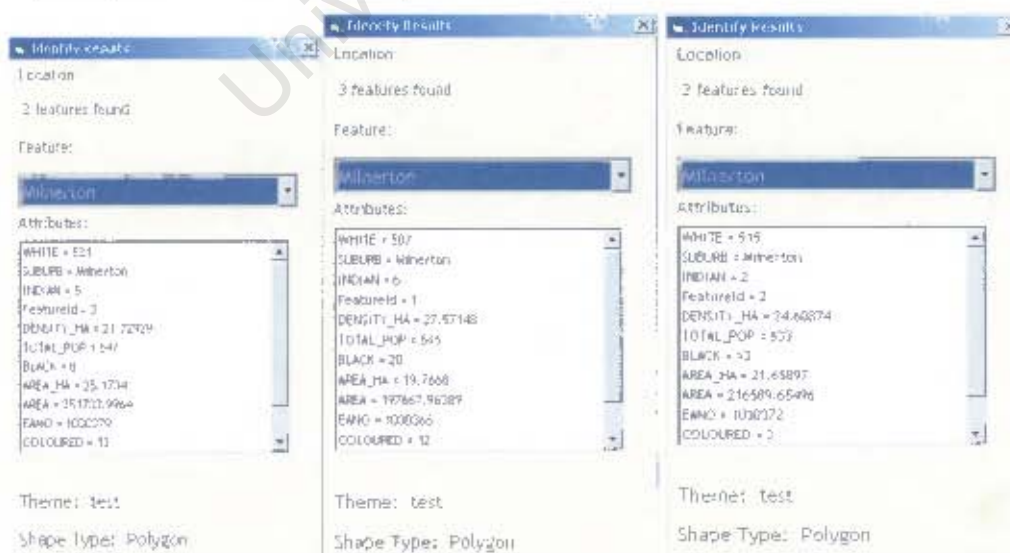


Figure 5.3: Attributes of the selected population tracts

From Figure 5.3, it can be deduced that approximately 1685 people stay within 100 metres from the stop. This kind of information is used to assess how well the stops are serving the customers. It can also be used to estimate the ridership statistics for a proposed stop location; this would be even more effective if information on car ownership is available for each area.

5.4. Shortest path analysis

One of the most important applications of spatial information systems in transport is the calculation of the optimal path between two any points marking the start and end points of a proposed route. This helps when public transport operators need to reassign public transport vehicles to more efficient routes, that is routes that are less congested and take less time to traverse through. In the Visual Basic application, the only kind of shortest path analysis that can be performed is that based on the length of each road section (see Appendix D for an example).

In ArcInfo, the cost of travelling along a network linear feature is based on the weight assigned to it. By default, the weight is the length of that network linear feature. Otherwise, the designer can include other weights. In this research, the following weights are considered:

- The volume of traffic in each segment of the road for the three different peak periods, that is the morning peak (am peak), during the day (off peak) and the evening peak (pm peak).
- Time delays along each segment of the road based on the maximum speed allowable for the road segment. This time is calculated by dividing the length of each road section by the maximum allowable speed along that road, that is,
$$\text{Time} = \frac{\text{Length(m)}}{\text{Speed(ms}^{-1}\text{)}}$$
- Time delays incurred when a vehicle waits for its turn to cross an intersection, either a signalised intersection (one with traffic lights) or an unsignalised (one without traffic lights) intersection.

The spatial information system developed in this research contains a module that can be used to enter all the required parameters, and it calculates the delay in seconds for each directional approach at the intersection. This delay can then be assigned to corresponding intersection junctions. The discussion of the formulae used for calculating the delay and can be referred to in Appendix C. The procedure for performing Network Analysis is provided in the software manual in Appendix D.

An important point to note is the fact that a different route can be obtained for different times of the day based on the volume of traffic in the road at that time of day. For example, in Figure 5.4 and Figure 5.5, different shortest paths were created from the same start and end point by using different weights. Figure 5.4 shows the shortest route obtained by assigning the weight to be the volume of traffic along each section of the route during the AM peak.

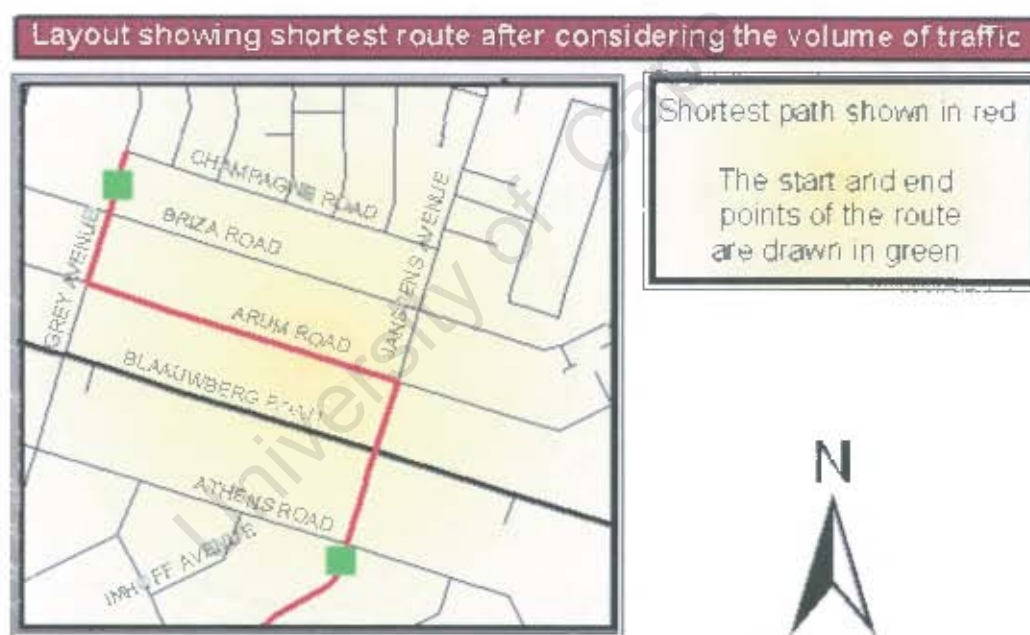


Figure 5.4: Shortest route between two points

Figure 5.5 shows a different route for the same start and end points, after changing the weight from AM Peak volume to the time taken to traverse along a section of the road based on the maximum allowable speed for that road section.



Figure 5.5: Shortest time route between two points

5.5. Ride check survey analysis

Ride check survey analysis presents the results of the ride check survey carried out in Cape Town in the year 2000. The information can be obtained per section of a route, for different stops or aggregated for the whole route, depending on the kind of analysis being performed. The information can be presented as text in reports or as graphs on maps. Figure 5.6 illustrates the amount of passengers who were travelling along each section of the route during the ride check survey.

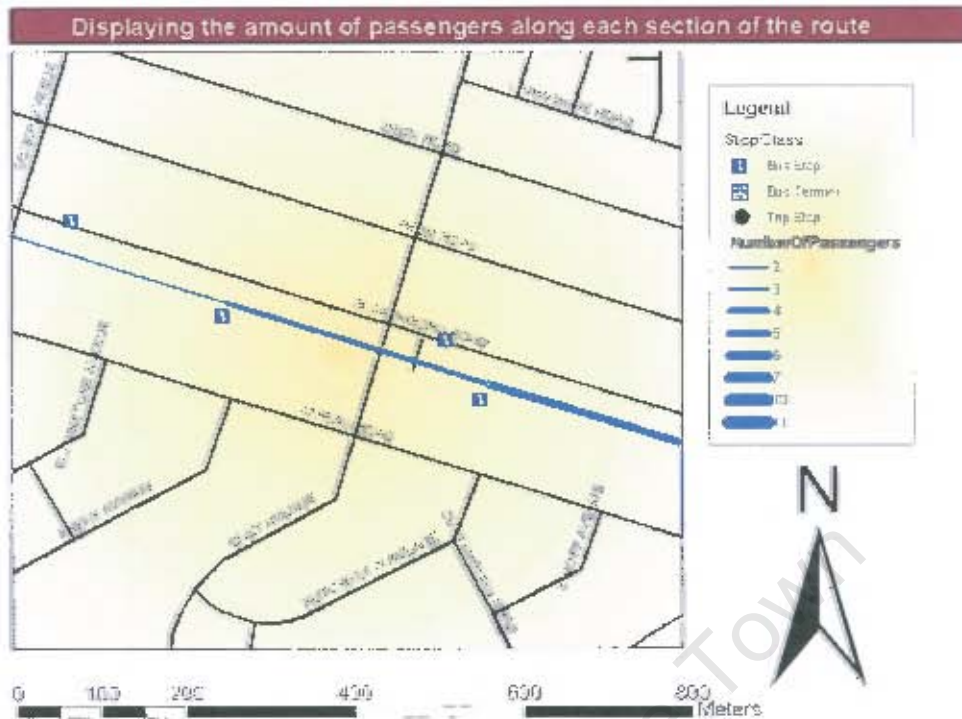


Figure 5.6: The amount of passengers travelling along sections of a route.

By clicking on a stop, information can be obtained on the amount of passengers boarding and getting off at each stop, the number who paid by cash, the number who paid by card and the arrival and departure times at each stop (see Figure 5.7).

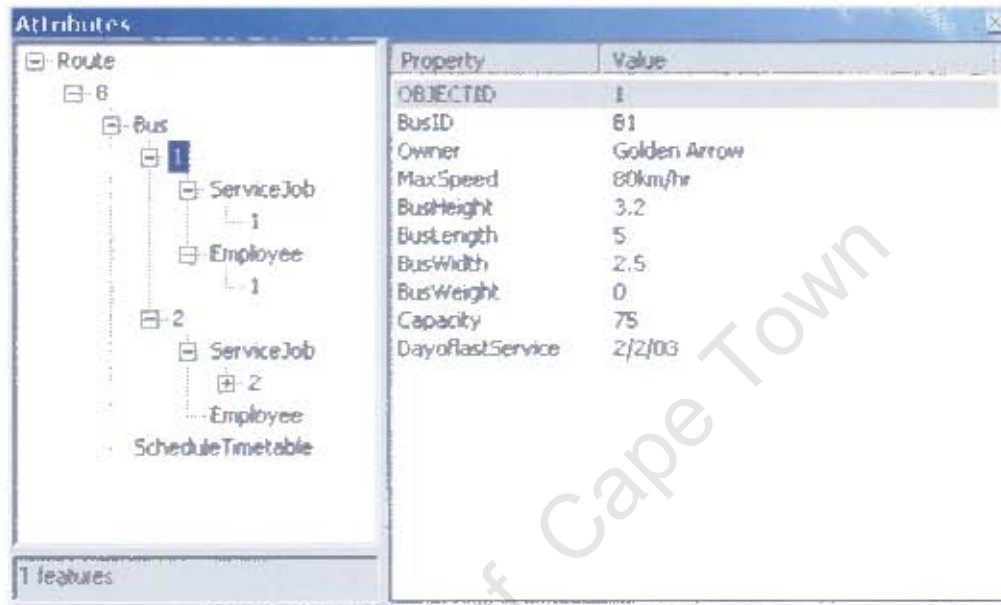
The screenshot shows a 'Attributes' window in a GIS application. On the left, a tree view shows the hierarchy: Stop (selected), Trip, and Road (BLAAUWBERG ROAD). The main area displays a table of attributes for the selected stop.

Property	Value
OBJECTID	1731
StopID	1617
StopName	526
PassengersBoarding	5
PassengersAlighting	3
StopClass	Bus Stop
Enabled	False
PassengersBoardingAMPeak	6
PassengersAlightingAMPeak	7
PassengersBoardingPMPeak	2
PassengersAlightingPMPeak	8
StopDescription	Along Atlantis to Cape Town Route
PassengerBoardingOFFPeak	5
PassengerAlightingOFFPeak	6
ArrivalTime	1:32:10 PM
DepartureTime	1:32:20 PM
PaidByCash	3
PaidByCard	2
RoadID	12840

Figure 5.7: Attributes of a selected stop

5.6. Other attribute queries

Clicking on a route and displaying the attributes of that particular route can retrieve information on the buses that travel on that route, the timetable, the description of the service jobs of the bus and information on the driver. Images of the bus and the bus driver can also be retrieved from the attributes (see Figure 5.8).



Property	Value
OBJECTID	1
BusID	81
Owner	Golden Arrow
MaxSpeed	80km/hr
BusHeight	3.2
BusLength	5
BusWidth	2.5
BusWeight	0
Capacity	75
DayoflastService	2/2/03

Figure 5.8: The attribute table of a selected route.

5.7. Summary

This chapter provided some of the functions that the developed prototype system can perform. More examples are in Appendices D. The developed system was tested on a sample of potential users and the testing procedure and results are presented together in the conclusions in Chapter Six together with the recommendations.

Chapter Six

Conclusions and recommendations

6. Introduction

In Chapter One, specific objectives were stated for this research. In this chapter, the research is consolidated with an evaluation of which of the objectives have been fulfilled and to outline difficulties that have been encountered during the process. From this discussion, conclusions are drawn and recommendations made for future research.

6.1. Conclusions

The first specific objective: “To develop a data model for public transport information management”

To fulfil this objective, the following research questions were answered:

Question One: What kind of public transport information has to be managed and how is it acquired?

Public transport information is mostly spatial in nature. The information, as discussed in Chapter One, is mainly obtained from the public transport surveys that are carried out regularly¹⁵ to assess and improve public transport services. Specifically mentioned, was the ride check survey carried out in Cape Town, South Africa in 2000. During this survey, a surveyor boarded a bus for the duration of a trip carrying a GPS receiver and a palm pilot. The GPS receiver collected location data and the palm pilot electronically recorded all the data collected.

Since the accuracy of information that is obtained from the system depends on the quality of the data that has been used, the data requirements for the system should inform the data collection and survey process.

¹⁵ But sometimes it is not as often as should be, due to financial constraints.

Question Two: What are the different approaches used in creating data models for public transport information management, which data model will be used and why?

In Chapter Three, it has been discussed that generally, in creating a data models for spatial information systems, one could either use the network model, the hierarchical model, the relational model, the object-oriented model or the object-relational model. In terms of spatial information systems for public transport information management, the conclusion reached in Chapter Two, the literature review, was that the relational model has been used in most systems. Some of the advantages of the relational model are discussed in Chapter Three. These include the simplicity of the model and the fact that it is based on a well-developed mathematical theory of logic and relations.

Despite its popularity in applications that use data that can be represented using integers and strings, the relational model as discussed in Chapter Three, is insufficient in representing the complex data in spatial information systems. Due to the shortcomings of the relational model also discussed in Chapter Three, researchers are moving for the object-oriented and object-relational models. After discussing the advantages and disadvantages of the object-oriented model, the object-relational model as the most suitable model to use in this research. The design of this type of data model is explained in Chapter Four, with the presentation of the conceptual and the logical data models.

The second specific objective: “To develop a prototype spatial information system for Blaauwberg Municipality, Cape Town”

To fulfil this objective, the following research questions were answered:

Question Three: Which geographic information software is to be used and how are the physical databases created and features represented in this software?

Chapter Five provides a discussion on the development of the prototype for Blaauwberg Municipality using the ESRI ArcInfo Version 8.2® software. ArcInfo was selected because it was the only software available that supports the object-relational model. Using UML, a schema of the data model is created by modifying the ArcGIS

Transportation Data Model. The created schema was then exported to a Microsoft Repository. The created Microsoft Repository was imported into ArcCatalog and a geodatabase was created. Projection parameters were set for the geodatabase as well as the relationships between the objects.

In ArcInfo, the roads are represented as network features, the routes are modelled as linear features through dynamic segmentation with trip paths being events of the routes, and the stops are represented as point features. The other non-spatial elements of the data model are represented as tables and relationships are modelled as relationship classes.

Question Four: Does the software allow for any customisation if necessary?

Removing unnecessary functions and adding in new functions by writing programming code using Visual Basic for Applications can easily customise ArcMap. Examples of the customisation performed in ArcMap for the prototype are:

- The removal of some unnecessary functions;
- The adding of the password dialog box that is presented to the user at any attempt to edit the prototype database and spatial features; and
- The addition of the intersection delay calculation forms to the prototype (see Appendix C for representation of the forms).

Besides creating the prototype in ArcMap and customising it, a decision was made to create a stand-alone application with an easy to use graphic user interface, using ESRI MapObjects 2.0 and Microsoft Visual Basic Version 6.0. This application is mostly for information retrieval and simple queries. Editing of the database and more involved shortest path analysis can only be performed in ArcMap.

The stand-alone application was distributed to transport professionals for assessment. Five people were selected to test the software. Although a small sample size was used, the qualifications of people involved ensured that a reasonable feedback could be obtained. A deliberate attempt was made to select people who have never used similar

software before, because such people would not be aware of the advanced functions of typical spatial information system software and would inform its user-friendliness. Among those selected were:

- Two transport planning and engineering lectures;
- One transport planning researcher; and
- Two transport engineering postgraduate students.

The software was set up on each person's computer. Each person had to go through the software and fill in a questionnaire (see Appendix E for a sample questionnaire). Based on the questionnaire, the results presented in Figure 6.1 were obtained.

User-friendliness of the system



Figure 6.1: User-friendliness of the software.

From Figure 6.1, of the five people who used the software, 40% said it was very user friendly and 60% responded that it was quite user friendly. What made the software hard to follow is the use of certain terms, which only a regular GIS software user would be familiar with. Such terms as 'spatial queries' and 'shortest path analysis' were, in most cases unexplained and therefore unclear to them what they represented. These terms were later changed to 'Map based queries' and 'Find shortest path' in the final executable.

Easiness of use of the manual

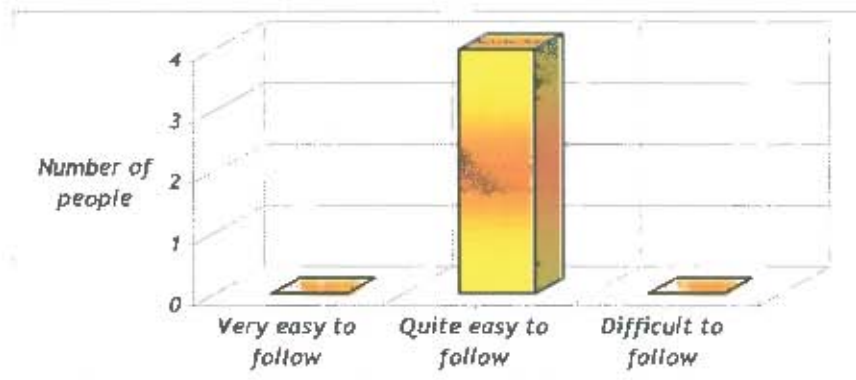


Figure 6.2: Easiness of use of the software manual.

The software manual assumes prior knowledge of the kind of functions a GIS can perform and words such as 'map panning', 'table of contents' made some of the instructions unclear. Some attributes like 'FeatureID' were not explained and therefore the users could not determine their meanings.

Difficulties encountered in using the software

The major difficulty, which was incurred by two people, arose from the fact that when the software was set up on each of the computers, it was set up in a directory that was different from the one in which the database was created in. This meant the reports and graphs failed to connect and retrieve data from the database and therefore the users got error messages on attempting to open graphs or reports. This problem had been anticipated prior to distribution and a set of instructions had been issued for troubleshooting. It seems these instructions did not work or were not clear. However, this has been rectified in the final executable file.

Other difficulties were the fact that for some analysis, the software did not give one an option to return to the previous window. This was rectified in the final executable.

Suggestions

The following suggestions were made for the system:

- It should include passenger analysis for different times of the week.

-
- ❑ Distribute the software to more users for them to find any bugs in the software.
 - ❑ A clearer user manual should be designed for use with the software.
 - ❑ Include an on-line help function that can be accessed by the click of a button instead of a printed one.

Comments

Some of the comments received were:

- ❑ A good data management tool; and
- ❑ An interesting concept.

It would have been ideal to observe each of the testers as they assessed the software and make note of any difficulties faced and the specific problem functions. When a tester is alone and they encounter problems, they would rather try to work around it or just omit that particular section. If they fail to find a solution, they will not state it in the questionnaire just in case it reflected on their ignorance. But due to time constraints, this was not possible.

The overall objective- “To design a prototype spatial information system for public transport information management,” was achieved. Based on the test results presented above, it is quite a user-friendly system. The main advantage of the system is that most of the queries are predefined and ready for output and the user does not see the underlying database. The stand-alone application can run on any Windows Operating System, it was tested on Windows 2000 Professional and Windows 98 with the same results. No special software is required to run it. ArcMap is only required for performing advanced shortest path analysis.

As the data model used for the system is based on the object-relational model, it can be used in software products that use relational databases. For example, anyone using Microsoft Access® or ESRI ArcView® can use the same data model. The data model is general to public transport and so the other modes of public transport can also be added into the system. Any other survey data available, for example the data from passenger counting at termini or the data from the bus transit surveys is also supported by the

system. It can also be used in other provinces outside the Western Cape, without any alterations.

If the system were implemented in Cape Town, it would offer the following benefits, in line with the relevant policies included in the White Paper on National Transport Policy (1996):

- The ability to offer an integration of information on the different public transport modes in one system, which can improve the co-ordination and efficiency of public transport;
- The accessibility analysis component would help in assessing the efficiency of existing stops and the public transport routes; and
- The shortest path analysis can be used in the creation of new routes with less congestion and delays so as to minimise travel times for the public transport user.

6.2. Recommendations for future research

In creating the data model using the object-relational model, created objects inherited properties from the custom ArcInfo classes. Further research should commence on the addition of triggers¹⁶ to the data model. An example is a trigger that automatically causes edits to related objects when one of the related objects is edited, by using the messaging between objects. For example, if a route is deleted, then the related trip paths are automatically deleted because a trip path cannot exist without the routes in the database.

Even though user forms were designed for calculating the shortest path using intersection delay, these modules were not tested with real data. Also, the actual shortest path calculations using these delays were not calculated. Further research could be on calculating the shortest path using these delays and comparing them with the existing scenario. This requires more detailed data on the volumes of traffic going in the various directions at an intersection. One way of obtaining this data is through intersection traffic counts.

¹⁶ A trigger is an action causing the automatic invocation of a procedure.

The selection of the formulae used for calculating intersection delay was based on availability and alternative formulae were not explored. Further research could be on analysing each of the formulae, establish the pros and cons of each and then possibly finding more suitable formulae and testing them with ESRI ArcInfo®.

The feedback gathered from talking to a number of transport professionals and service planners is that a word they often have in mind is 'transport modelling'. Besides managing public transport information and displaying it, they are more concerned with transport modelling, the results of which assist in their planning. An example of a model popularly used is the Four-Step Model. This model is applied to forecast future travel patterns and design appropriately. For the information management tool designed in this research to be accepted in the transport community, a program could be written for such a model, attached to the system and any results can be managed and displayed on the system's maps.

The designs of most systems implemented in industry involve a large team comprising system analysts, computer programmers and software quality testers. The design process is also a cyclic procedure, involving feedback from potential users at each stage and making the necessary amendments. With this in mind, the researcher cannot attest to the fact that the system they have developed is perfect. The only anticipation is that the development of this system opens doors to further research questions and any further developments can be based on its improvement.

References

- ADAMS, T.M., VONDEROHE, A.P., BUTLER, J.A., KONCZ, N. (1999) 'Model Considerations for a Multimodal, Multidimensional Location Referencing System,' in *Proceedings GIS-T 1999 Symposium, San Diego, March 1999* [Online]. [Accessed 12 June 2002]. Available from the World Wide Web <http://www.bts.gov/gis/BTSWEB/GIS-T_99/Session_21/211.html>
- AfriGIS. (2000) *The CMC and AfriGIS Breaking new ground with TransCAD GIS Software*. Press Release. [Online]. [Accessed 15 August 2002]. Available from the World Wide Web <http://www.afrigis.co.za/site/Default_news.htm>
- ALTERKAWI, M. (2001) Applications of GIS in Transportation Planning: The Case of Riyadh, the Kingdom of Saudi Arabia. *GBER* 1(2), pp 38-46
- ARCINFO USER GUIDE. (1991) *Dynamic Segmentation: Modelling Linear Features*. Environmental Systems Research Institute, Inc.
- ATTANUCCI, J.P., HALVORSEN, R. (1999) *What GIS can do for transit planning*. Multisystems Inc. Massachusetts. [Online]. [Accessed 15 July 2002]. Available from the World Wide Web <<http://www.fta.dot.gov/library/technology/symops/Attanucc.htm>>
- AUCAMP, C.A, SHAW, A. (2001) 'The fundamental restructuring of Durban's public transport system,' in *Proceedings, 20th South African Transport Conference, South Africa, 16-20 July 2001*.
- BANCILHON, F. (1988) Object-Oriented Database Systems. *Association for Computing Machinery*.
- BANCILHON, F. (1996) 'Object Databases,' in *Proceedings Conference on Object Orientation and Navigable Databases, March 15-16 1996*.
- BOTES, F., GORDGE, R.M., HOLTZHAUZEN, L. (2001) 'Public transport fares rationalization for Cape Town,' in *Proceedings, 20th South African Transport Conference, South Africa, 16-20 July 2001*.
- BRITZ, C., DU PLESSIS, M. (2001) 'Restructuring of the public transport system in Gauteng through masterplanning and tendered bus contracts,' in *Proceedings, 20th South African Transport Conference, South Africa, 16-20 July 2001*.
- CERF. (1999) *Efficiency in Action: Saving Time, Money and the Environment*. [Online]. [Accessed 20 February 2002]. Available from the World Wide Web <<http://www.cerf.org/iiec/news/121997/i8.htm>>

-
- CHEN, P.P.S. (1976) The Entity Relationship Model-Towards a unified view of data. *Association of Computing Machinery Transactions on Database Systems* 1(1), pp 9-36
- CLARKE, P., CROUS, W. (2001) 'A Strategic Review of Public Transport User Needs in the Cape Metropolitan Area,' in *Proceedings Thredbo 7 Conference 2001*, 18 April 2001
- CLIMATE CHANGE. (2001) Mitigation. Intergovernmental Panel on Climate Change [Online]. [Accessed 17 April 2002]. Available from the World Wide Web <<http://www.ipcc.ch/pub/tar/wg3/368.htm#928>>
- CLODOVEU, A.D. JR. (1994) Object-Oriented GIS in practice. *Urban and Research Information Association*, pp786-795
- CODD, E.F. (1970) A relational model of data for large shared data banks in *Communications of the ACM*, 13(6).
- CONNOLLY, T., BEGG, C. (2002) *Database Systems- A Practical Approach to Design, Implementation, and Management*. 3rd Edition, United States of America: Addison Wesley
- COOPER, R. (1997). *Object Databases: An ODMG Approach*. England: International Thomson Computer Press.
- DATE, C.J. (1995) *An Introduction to Database Systems*. 6th Edition, Addison-Wesley Publishing, Inc
- DE SAINT LAURENT, B. (1998) 'Overview of Urban Transport in South Africa,' in *Proceedings 8th CODATU Conference. Cape Town, September 1998*. [Online]. [Accessed 15 March 2002] Available from the World Wide Web <<http://www.dbsa.org/privatesector/ppinote6.htm>>
- DEPARTMENT OF TRANSPORT. (2002) *Moving South Africa*. South Africa [Online]. [Accessed 20 April 2002]. Available from the World Wide Web. <<http://www.transport.gov.za/projects/msa/msareport/msadraft83.html>>
- DEVARAKONDA, R.S. (2001) Object-Relational Database Systems- The Road Ahead. *ACM Crossroads Student Magazine March 2001*. [Online]. [Accessed 15 August 2002]. Available on the World Wide Web <<http://www.acm.org/crossroads/xrds7-3/ordbms.html>>
- DRANE, C., RIZOS, C. (1998) *Positioning systems in intelligent transportation systems*. London: Artech House Inc.
- EDWARDS, J.D. (1992) *Transportation Planning Handbook*. Institute of Transportation Engineers: Prentice Hall Inc.

-
- EGENHOFER, M.J. (1992) Object-Oriented modeling in GIS. *Urban and Regional Information Association*, 4(2), pp3-19
- EGENHOFER, M.J. (1996) 'Object-Oriented Needs for Navigable Databases,' in *Proceedings Conference on Object Orientation and Navigable Databases, March 15-16 1996*.
- ETCHES, A., PARKER, D., INCE, S., JAMES, P. (2000) 'UTIS (Urban Transportation Information System) A Geo-Spatial Transport Database,' in. *ACM Symposium on GIS, Washington D.C., November 2000*.
- FHWA (2000). *Case Study: Orange County, California*. U.S. Department of Transport, Federal Highway Administration. [Online]. [Accessed 12 June 2003] <http://www.fhwa.dot.gov/planning/toolbox/orange_context.htm >
- FLETCHER, D. (1996) 'Navigating in a digital object habitat,' in *Proceedings Conference on Object Orientation and Navigable Databases, March 15-16 1996*.
- FLOWERDEW, R. (1991) 'Spatial Data Integration,' in Goodchild M. F., Maguire J. M., Rhind D.W. (eds), *Geographical Information Systems, Volume 2: Management Issues and Applications, First Edition*. Longman Scientific and Technical.
- FORGEY, H., DIMANT, T., CORRIGAN, T., MOPHUTHING, T., SPRATT, J., PIENARR, D., PETER, N. (2001) *South Africa Survey 2000/01*. South African Institute of Race Relations.
- FRANK, A.U. (1996) 'Object-Oriented Modeling,' in *Proceedings Conference on Object Orientation and Navigable Databases, March 15-16 1996*.
- FRANKLIN, M.J. (1996) 'The Object Relational Manager,' in *Proceedings Conference on Object Orientation and Navigable Databases, March 15-16 1996*.
- GALITZ, W.O. (1989) *Handbook on Screen Format Design*. 3rd Edition, United States of America: QED Information Sciences, Inc.
- GEITNER, K., SONNE, P (1999) 'Using GIS in Planning, Production and Analysis of Public Transportation,' in *Proceedings ESRI European User Conference November 15-17 Munich, Germany* [Online]. [Accessed 15 January 2002]. Available from the World Wide Web. <<http://gis.esri.com/library/userconf/europroc99/html/vortraege/v08/v0802/v0802.html>>
- GOODCHILD, M.F. (1996) *Geographical Information Systems and Disaggregate Transportation Modeling*. [Online]. [Accessed 15 October 2001]. Available on the World Wide Web. <<http://www.ncgia.ucsb.edu/vital/research/pubs/mfg9607.pdf>>
- GOODCHILD, M. F. (1999) 'GIS and Transportation: Status and Challenges,' in *Proceedings International Workshop on Geographic Information Systems for*
-

-
- Transportation (GIS-T) and Intelligent Transportation Systems (ITS). Hong Kong* [Online]. [Accessed 12 December 2001] Available on the World Wide Web
<http://www.jlgis.cuhk.edu.hk/-Academic-GIS-T/GISTpaper/1_goodchild/GOODCHIL.DOC>
- HARRINGTON, J.L. (2000) *Object-Oriented Database Design Clearly Explained*. Morgan Kaufman publishers. Academic Press.
- HAWRYSZKIEWYCZ, I.T. (1994) *Introduction to Systems Analysis and Design*. Third Edition, Australia: Prentice Hall
- HEALEY, R.G. (1991) 'Database Management Systems,' in Goodchild M. F., Maguire J. M., Rhind D.W. (eds), *Geographical Information Systems, Volume 2: Management Issues and Applications*, First Edition. Longman Scientific and Technical.
- HOWE, D. R (1989) *Data Analysis for Database Design*. Second edition, London: Edward Arnold.
- HUGHES, J.G. (1991) *Object-Oriented Databases*. First Edition, London: Prentice Hall International.
- INCE, D. (1995) *Software Quality Assurance: A Student Introduction*. England: McGraw-Hill Publishing Company.
- LAURINI, R., THOMPSON, D. (1996) *Fundamentals of Spatial Information Systems*. Academic Press Limited.
- LEE, J. S., BAUMGARTNER, J.A., KIM, T. J. (1999). 'A Web-based Bus Information System,' in *Proceedings, 19th Annual ESRI International User Conference, San Diego, California*. [Online]. [Accessed 19 February 2003]. Available on the World Wide Web
<<http://gis.esri.com/library/userconf/proc99/proceed/papers/pap494/p494.htm>>
- LOMBARD, M.C., LAMPRECHT, T., VAN ZYL, N.J.W. (2001) 'Fundamental Restructuring of Durban's Public Transport System- The User Preference Study,' in *Proceedings, 20th South African Transport Conference, South Africa, 16-20 July 2001*.
- LOUW, J.J., VAN ZYL, N.J.W., MEINTSMA, J. (2001) 'Development of a public transport management information system to assist decision-making in the restructuring of public transport in Durban,' in *Proceedings 20th South African Transport Conference, South Africa, 16-20 July 2001*.
- MACPHERSON, G. (1993) *Highway and Transportation Engineering and Planning*. First Edition, Longman Scientific and Technical.

-
- MADDISON, D., PEARCE, D., JOHANSSON, O., CALTHROP, E., LITMAN, T., VERHOEF, E. (1996) *The True Costs of Road Transport*. Earthscan Publications Ltd.
- MCQUEEN, B., MCQUEEN, J. (1999) *Intelligent Transportation Systems Architectures*. London: Artech House Inc.
- MILLER, H.J., STORM, J.D. (1996) Geographical Information Systems for Network Equilibrium-based travel demand models. *Transport Research Part C*, 4 (6) pp.373-389.
- MILLER, H.J., SHAW, S.L. (1999) 'GIS-T Data Models,' in *Geographical Information Systems for Transportation: Principles and Applications*, Oxford University Press. [Online]. [Accessed 16 October 2001]. Available on the World Wide Web <http://www.gisvisionmag.com/Book/miller_shaw.pdf>
- MILNE, P., MILTON, S., SMITH, J.L. (1993) Geographical object oriented databases – a case study. *International Journal of Geographical Information Systems* 7 (1), pp. 39-55.
- MOVING AHEAD. (2001) *City of Cape Town Transport Plan, Part 2: Public Transport-Operational Component*. City of Cape Town: Creative Services
- NATIONAL DEPARTMENT OF TRANSPORT. (1999) *Moving South Africa*. [Online]. [Accessed 15 January 2001]. Available from the World Wide Web. <<http://www.transport.gov.za/projects/msa/index.html>>
- ORTÚZAR, J. DE D., WILLUMSEN, L.G. (1994) *Modelling Transport*. 2nd Edition, England: John Wiley and Sons Ltd
- PAPACOSTAS, C.S. (1995) *GIS Application to the Monitoring of Bus Operations* [Online]. [Accessed 12 December 2001]. Available from the World Wide Web <<http://www.eng.hawaii.edu/~csp/Mygis/busgis.html>>
- PAPACOSTAS, C.S, PREVEDOUROUS, P.D (1993) *Transportation Engineering and Planning*. Second Edition. Prentice Hall Inc.
- PILLAY, K. (2001) 'The South African Public Transportation Professional,' in *Proceedings, 20th South African Transport Conference, South Africa, 16-20 July 2001*.
- SAAKE, G., CONRAD, S., SCHMITT, I., TÜRKER, C. (1995) 'Object-Oriented Database Design: What is the Difference with Relational Database Design?' in *Proceedings, ObjectWorld Frankfurt October 11 1995. Software Development Track SD.6, 1995*.
- SALTER, Y., HOUNSEL, N.B. (1996) *Highway Traffic Analysis and Design*. Third Edition. MacMillan Press

-
- SCHWEIGER, C.L. (1992) Current use of Geographical Information Systems in Transit Planning. *Transportation Research Record 1349*, 1992, pp. 93-106.
- SHAW, S. L. (1999) 'Handling Disaggregate Travel Data in GIS,' in *Proceedings International Workshop on Geographic Information Systems for Transportation (GIS-T) and Intelligent Transportation Systems (ITS)*. Hong Kong April 26-28, 1991 [Online]. [Accessed 15 August 2002] Available from the World Wide Web <[http://www.jlgis.cuhk.edu.hk/Academic/GIST/GISTpaper/9 Shih lung Shaw/HK-GIST-.DOC](http://www.jlgis.cuhk.edu.hk/Academic/GIST/GISTpaper/9%20Shih%20lung%20Shaw/HK-GIST-.DOC)>
- SHEKHAR, S. (1996) 'GIS-T Navigable Databases: A conceptual model and challenges in using object models,' in *Proceedings Conference on Object Orientation and Navigable Databases, March 15-16 1996*.
- SHEPHERD, I.D.H (1991) 'Information Integration and GIS,' in Goodchild M. F., Maguire J. M., Rhind D.W. (eds), *Geographical Information Systems, Volume 2: Management Issues and Applications*, First Edition. John Wiley and Sons
- SHEPPERD, M. (1995) *Foundations of Software Measurements*. First Edition, Great Britain: Prentice Hall.
- SIMMONS, J.B., WOOD, R., BOWMAN, R., AUCAMP, C.A. (2001) 'Development of a least cost strategy for Durban's public transport system,' in *Proceedings, 20th South African Transport Conference, South Africa, 16-20 July 2001*.
- SOULYRETTE, R.R., STRAUSS, T.R. (2000) 'Transportation,' in Easa S., Chan Y. (eds), *Urban Planning and Development Applications of GIS*. American Society of Civil Engineers.
- THANESUEN, S. (2002) *A Study on the Alternative Decision-Making Approach to New Schemes of Transportation in Bangkok Metropolitan Area*. MSc Thesis, Hokkaido University.
- THILL, C. (2000) *Geographic Information Systems for Transportation in Perspective. Transport Research Part C*, 8 (2000) pp.3-12.
- THOMPSON, R., WANG, Y., BISHOP, I. (1999) 'Integrating GIS with Intelligent Transport Systems and stochastic programming for improved vehicle scheduling,' in *Proceedings of Computers in Urban Planning and Urban Management: on the edge of the millenium, Venice*.
- TIWARI, D. (2001) 'Urban Transport Priorities meeting the challenge of socio-economic diversity in cities-case study Delhi, India,' in *Proceedings, 20th South African Transport Conference, South Africa, 16-20 July 2001*.

-
- TRÉPANIÉ, M., CHAPLEAU, R. (2001) Linking Transit Operational Data to Road Network with a Transportation Object-Oriented GIS. *Urban and Regional Information Association*, 13 (2).
- WANG, D., CHENG, T. (2001) A spatio-temporal data model for activity-based transport demand modeling. *International Journal of Geographical Information Science* 15 (6), pp. 561-585.
- WATERS, N. M (1999) 'Transportation GIS: GIS-T,' in Longley P. A, Goodchild M. F., Maguire J. M., Rhind D.W. (eds), *Geographical Information Systems Volume 2: Management Issues and Applications*, Second Edition. John Wiley and Sons
- WENDEL COX CONSULTANTS. (1996) *Urban Transport: From Theory to Reality. The Public Purpose*. July 1996. Number 11. [Online]. [Accessed 10 April 2002]. Available from the World Wide Web <<http://www.publicpurpose.com/pp-nz91.htm>>
- WILLITTS, J. (1992) *Database Design and Construction: An open learning course for students and information managers*. Great Britain: Library Association Publishing Ltd.
- WORBOYS M.F. (1994) Object-oriented approaches to geo-referenced information. *International Journal of Geographical Information Systems* 8 (4), pp. 385-399.
- WORBOYS, M.F. (1995) *GIS: A Computing Perspective*. Taylor and Francis Limited.
- WORBOYS, M.F. (1996) 'An approach to object modeling of a navigable database,' in *Proceedings Conference on Object Orientation and Navigable Databases, March 15-16 1996*.
- ZEILER, M. (1999) *Modelling Our World. The ESRI Guide to Geodatabase Design*. Environmental Systems Research Institute Inc.
- ZHONG, R.P. (1998a) *Internet GIS and its Applications in Transportation*. TR News March-April 1998
- ZHONG. R.P., GROFF. J.N., DUEKER. K.J. (1998b) An Enterprise GIS Database Design for Agency-Wide Transit Applications. *Urban and Regional Information Association*, 10 (2).

Bibliography

- CURTIN, K., NORONHA, V., GOODCHILD, M.F., GRISÉ, S. (2001) *ArcGIS Transportation Data Model (Draft)*. Environmental Systems Research Institute, Inc.

DEPARTMENT OF TRANSPORT (1996) White Paper on National Transport Policy
http://www.polity.org.za/govdocs/white_papers/transwhite.html Accessed
November 2001

MACDONALD, A. (1999-2001). *Building a geodatabase*. Environmental Systems
Research Institute, Inc.

PERRY, G (1998). *Teach yourself Visual Basic in 21 Days*. SAMS: A division of
Macmillan Computer Publishing.

ZAK, D. (1999). *Programming with Microsoft Visual Basic 6.0*. Course Technology.

University of Cape Town

Appendix A

Database data dictionary

University of Cape Town

1.0 Enterprise Rules

Road/MunicipalArea

- A road must be located in one municipal area.
- A municipal area may have one or more roads.

Road/Route

- A road may have one or more routes using it.
- A route may be located along one or more roads.

Road/Stop

- A road may have one or more stops.
- A stop must be located in one road.

Route/Timetable

- A route may have one or more timetables.
- A timetable must be for one route.

PublicTransportVehicle/Employee

- A driver may drive one or more buses.
- A bus may be driven by one or more drivers.

PublicTransportVehicle/ServiceJob

- A public transport vehicle may have one or more service jobs.
- A service job must be for one public transport vehicle.

Route/Trip Path

- A route may have one or more trip paths.
- A trip path must be in one route.

TripPath/Stop

- A trip path must begin and end at a stop.
- A stop may be the beginning or end of one or more trip paths.

Trip/Stop

- A stop may have one or more trips assigned to it.
- A trip may be assigned to one or more stops.

1.1. Skeleton Tables

- Road (RoadID,.....,MunicipalAreaID)
MunicipalArea (MunicipalAreaID,.....)

- Road(RoadID,.....)
Stop(StopID,.....,RoadID)

- Road(RoadID,)
Route (RouteID,.....)
Road/Route (RoadID, RouteID,.....)

- Route(RouteID,.....)
Timetable (TimetableID,.....RouteID)

- Route(RouteID,.....)
PublicTransportVehicle(VehicleID,.....)
Route/PublicTransportVehicle (RouteID, VehicleID,.....)

- Employee(EmployeeID,.....)
Public Transport Vehicle(VehicleID,.....)
Employee/Vehicle (EmployeeID, VehicleID,.....)

- PublicTransport Vehicle(VehicleID,.....)
ServiceJob (ServiceJobID,.....,VehicleID)

- Trip (TripID,.....)
Stop (StopID,.....)
Trip/Stop (TripID, StopID,.....)

□ Route (RouteID,.....)

TripPath (TripPathID,,RouteID, FromStopID, ToStopID)

1.2. Description of the entities

Before going into detail for each entity, it is important to know that each of the entities will have an attribute type called “ObjectID”. This is a system construct and is created for each object you create in the database. The ObjectID is unique for all objects in the database. For all the entities, besides the ObjectID, there is also another unique ID specified, for example RoadID, StopID and so on. This is a user specified ID. The reason for having this ID is that in some transport departments, employees would have been using their own unique IDs that they are familiar with and makes it easier for them to identify features.

1.2.1. Road

Attribute Type	Data Type	Description
Road Name	Text	It contains the name of each road
RoadID	Text	This is a user assigned unique ID, to each road.
Shape length	Double	The length of each road section in metres. It is automatically calculated in the system.
AMVolumeTo	Long Integer	Contains the amount of volume of traffic along that road section during the AM Peak in the direction towards Cape Town. This is used as a weight in Network Analysis.
AMVolumeFro	Long Integer	Contains the amount of volume of traffic along that road section during the AM Peak in a direction away from Cape Town. This is used as a weight in Network Analysis.
PMVolumeTo	Long Integer	Contains the amount of volume of traffic along that road section during the PM Peak in the direction towards Cape Town. This is used as a weight in Network Analysis.
PMVolumeFro	Long Integer	Contains the amount of volume of traffic along that road section during the PM Peak in the direction away from Cape Town. This is used as a weight in Network Analysis.

OFFVolumeTo	Long Integer	Contains the amount of volume of traffic along that road section during the OFF Peak in the direction towards Cape Town. This is used as a weight in Network Analysis.
OFFVolumeFro	Long Integer	Contains the amount of volume of traffic along that road section during the OFF Peak in the direction away from Cape Town. This is used as a weight in Network Analysis.
Road Class	Text	The type of road, whether it is a freeway or a major road.
Speed	Long Integer	The maximum speed limit for that road section
Enabled	Short Integer	It is an attribute type for each network feature. It contains either a true or false value. If it is set to false on any road, then it means that no Network traces can take place along that road section (that section is excluded from Network Analysis) otherwise the value is set to true.
Delay	Long Integer	Contains the time a vehicle will take to travel along that road section when travelling at 80km/hour. This is used as a weight in Network Analysis.
MunicipalAreaID	Text	Posted ID from the Municipal Area.

1.2.2. Stop

Attribute Types	Data Type	Description
StopID	Text	A unique user assigned ID.
StopName	Text	The name of the stop. As can be seen from the table, the City of Cape Town uses numbers as names for stops
PassengersBoarding	Long Integer	The number of passengers who got into the bus at that particular stop during the ride check survey.
ArrivalTime	Date	The time the bus arrived at that stop during the ridecheck survey.

DepartureTime	Date	The time the bus left that stop during the ridecheck survey.
PaidByCash	Long Integer	The number of people who paid by cash when they got into the bus.
PaidByCard	Long Integer	The number of people who paid by card when they got into the bus.
PassengersAlighting	Long Integer	The number of passengers who got off the bus at that particular stop during the ride check survey.
Stop Class	Long Integer	The type of the stop, whether it is a bus stop, a bus termini or a trip stop (that is an undesignated place where the bus stopped during the ride check survey).
PassengersBoarding AMPeak	Long Integer	An aggregated amount of the number of passengers who board the bus at that certain stop during the AM Peak period.
PassengersAlighting AMPeak	Long Integer	An aggregated amount of the number of passengers who get off the bus at that certain stop during the AM Peak period.
PassengersBoarding OFFPeak	Long Integer	An aggregated amount of the number of passengers who board the bus at that certain stop during the OFF Peak period.
PassengersAlighting OFFPeak	Long Integer	An aggregated amount of the number of passengers who get off the bus at that certain stop during the OFF Peak period.
PassengersAlighting PMPeak	Long Integer	An aggregated amount of the number of passengers who get off the bus at that certain stop during the PM Peak period.
PassengersBoarding PMPeak	Long Integer	An aggregated amount of the number of passengers who board the bus at that certain stop during the PM Peak period.
StopDescription	Text	A more textual description of the stop, containing information on the road along which it is located.
RoadID	Text	Posted ID from the road entity.

1.2.3. Route

Attribute type	Data Type	Description
BusRouteID	Text	A unique ID assigned to each route by the system when a route is created
BusRouteNumber	Text	A user assigned number for each bus route
Shape Length	Double	The length of each route in metres. It is automatically calculated in the system.
RouteName	Text	A user assigned name for the route
PassengersAMPeak	Long Integer	The amount of passengers travelling along the route during the AM Peak.
PassengersOFFPeak	Long Integer	The amount of passengers travelling along the route during the OFF Peak.
PassengersPMPeak	Long Integer	The amount of passengers travelling along the route during the PM Peak.
Route Description	Text	A more textual description of the route that is easier for anybody to understand.

1.2.4. Municipal Area

Attribute type	Data Type	Description
MunicipalAreaID	Text	A user assigned unique ID for each municipal area
MunicipalAreaName	Text	The name of the Municipal Area.

1.2.5. Trip

Attribute type	Data Type	Description
TripID	Text	A user assigned ID that uniquely identifies each trip.
Description	Text	The description of each trip

1.2.6. Trip Path

Attribute type	Data Type	Description
Recorddate	Date	The data of the ride check survey.
FromMeasure	Double	The measure on the route signalling the point along the route from which the path starts.
ToMeasure	Double	The measure on the route signalling the point where the path stops.
TripPathID	Text	A user assigned unique ID for each trip path.
BusRouteID	Text	A posted ID from the Route entity to signalling the route the path follows.
Number of Passengers	Long Integer	The number of passengers who travelled along that section of the road during the ride check survey.
FromStop	Text	The Stop ID of the stop from which the particular path begins.
ToStop	Text	The Stop ID of the stop at which the particular path stops.

1.2.7. Timetable

Attribute type	Data Type	Description
TimetableID	Text	A unique ID for each timetable.
BusRouteID	Text	A posted ID from Route entity providing information on the specific route for each timetable.
DepartureTime	Date	Scheduled departure time for the vehicle.
ArrivalTime	Date	Scheduled arrival time for the vehicle.

1.2.8. Service Job

Attribute type	Data Type	Description
BusID	Text	A posted ID from the bus entity. It provides information on which of the buses the service job refers to.

ServiceJobID	Text	A unique ID for each service job done on a bus.
Job description	Text	A description of the service work done.
Date of service	Date	The date on which the bus was serviced.

1.2.9. Bus

Attribute type	Data Type	Description
BusID	Text	A unique ID to describe each bus.
Owner	Text	The owner of the bus
MaxSpeed	Long Integer	The maximum speed the bus travels on.
Bus height, bus width, bus length and bus weight	Double	The height, width, length and weight of each bus.
Capacity	Text	The maximum number of passengers allowed on the bus.
DayoflastService	Text	Showing the day the bus was last serviced.

1.2.10. Employee

Attribute type	Data Type	Description
EmployeeID	Text	A user assigned unique identifier for each employee.
EmployeeName	Text	The name of the employee.
Address	Text	Where each employee lives.

Appendix B

UML Diagrams

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The domains

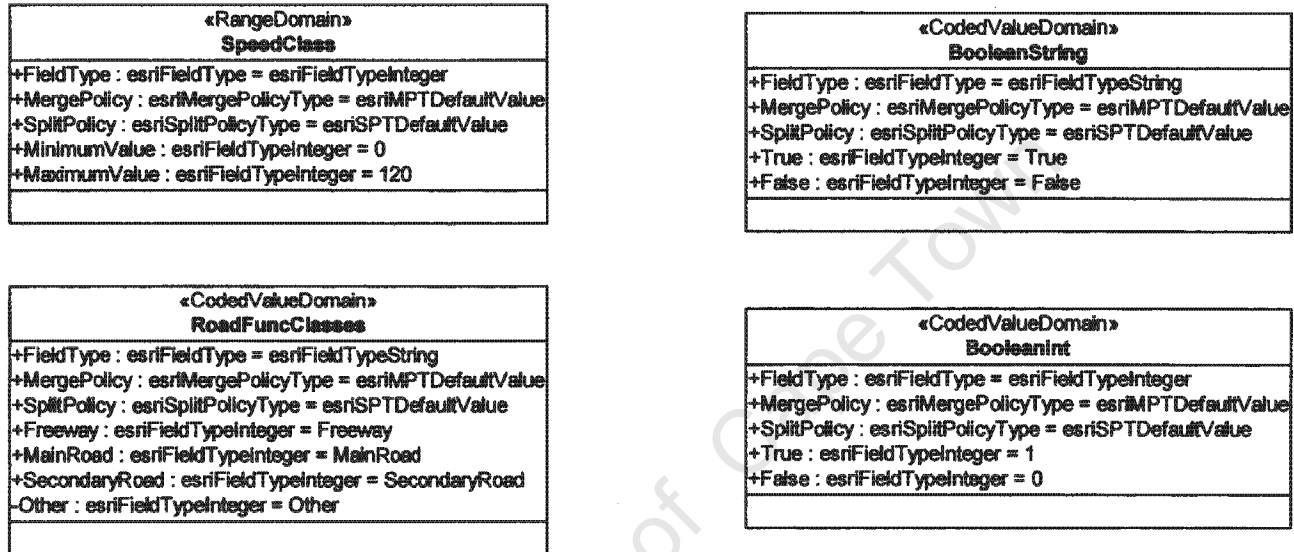


Figure 4: A schema showing all the domains created in the geodatabase

The route and stop features

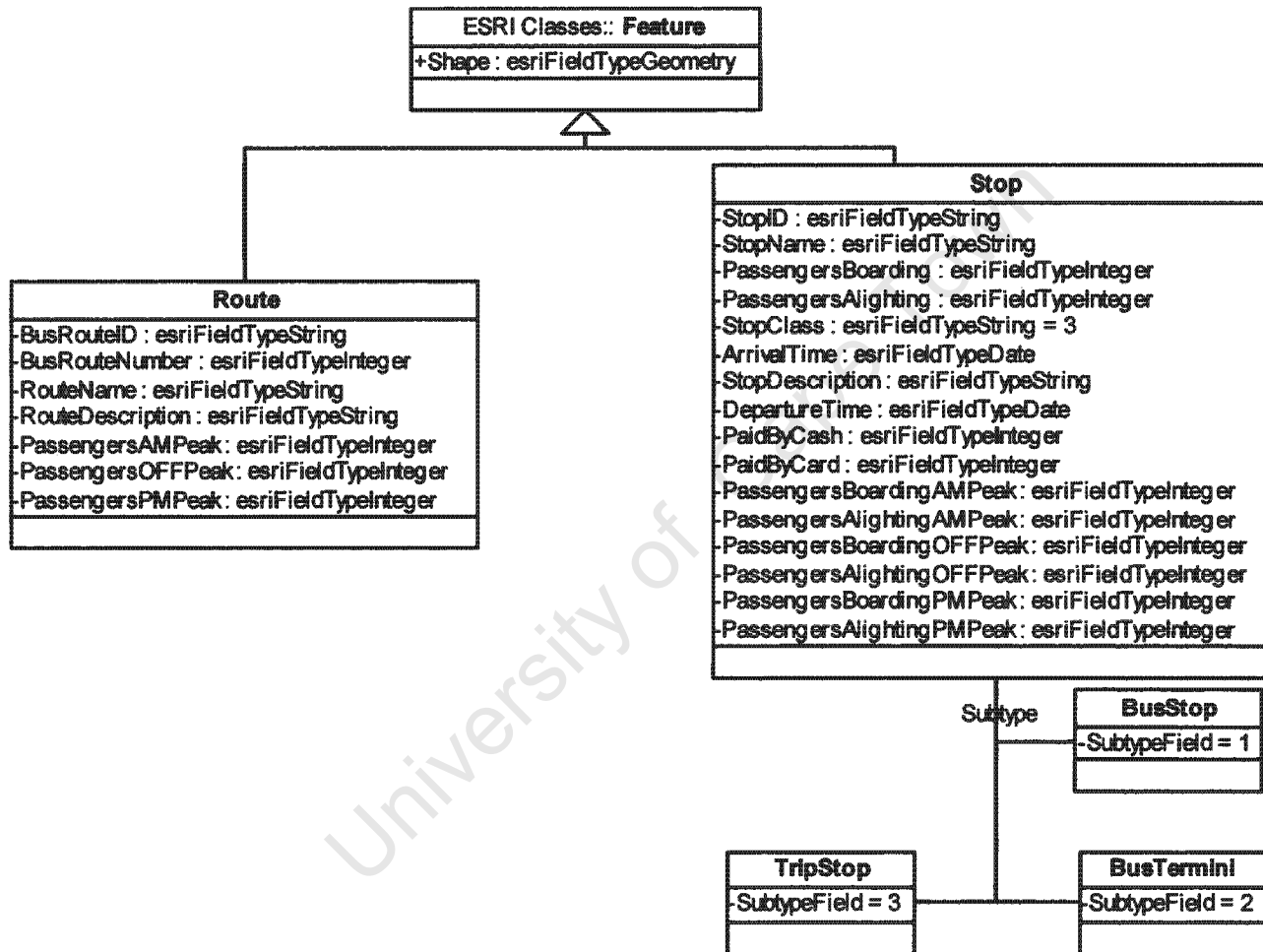


Figure 3: The public transport route and stop features schema

The non-spatial objects

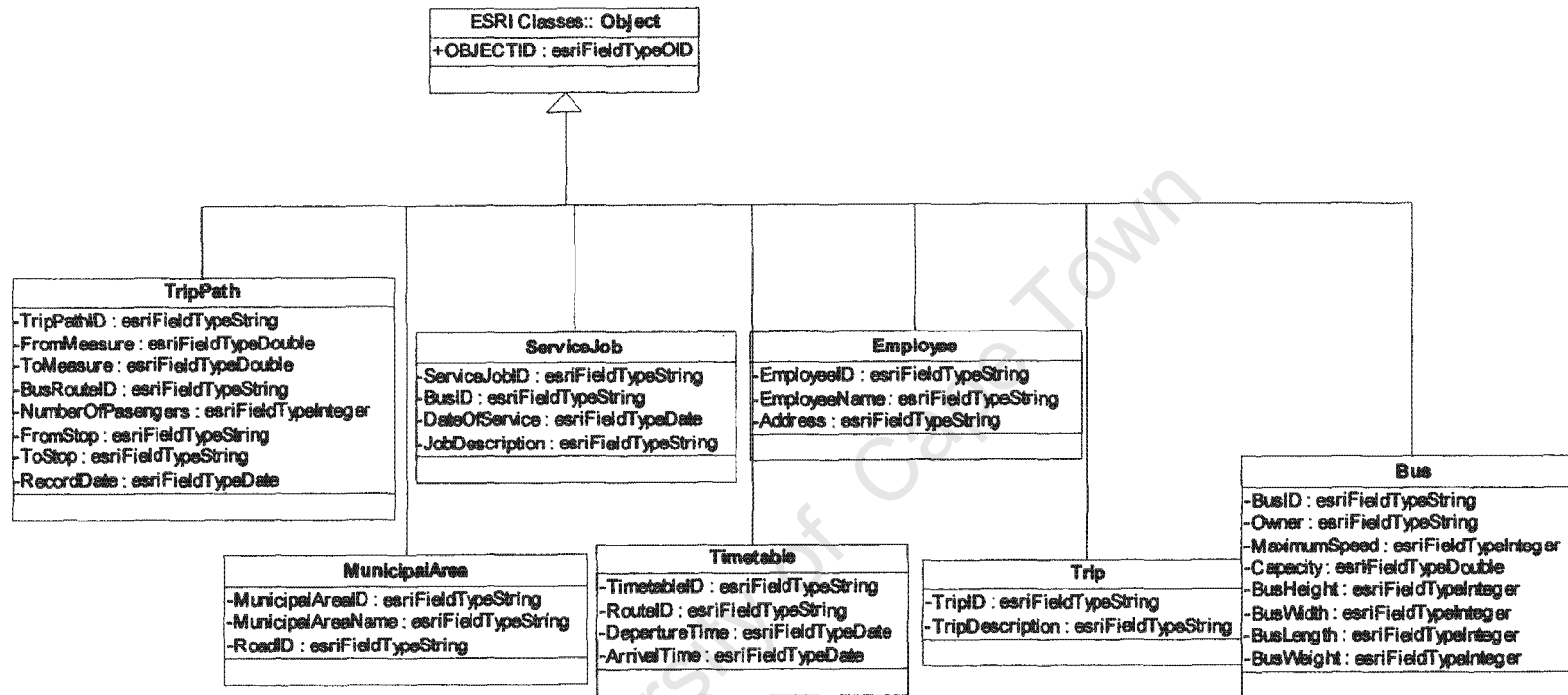


Figure 2: Non-spatial objects schema in UML Visio

The Public Transport Reference Network

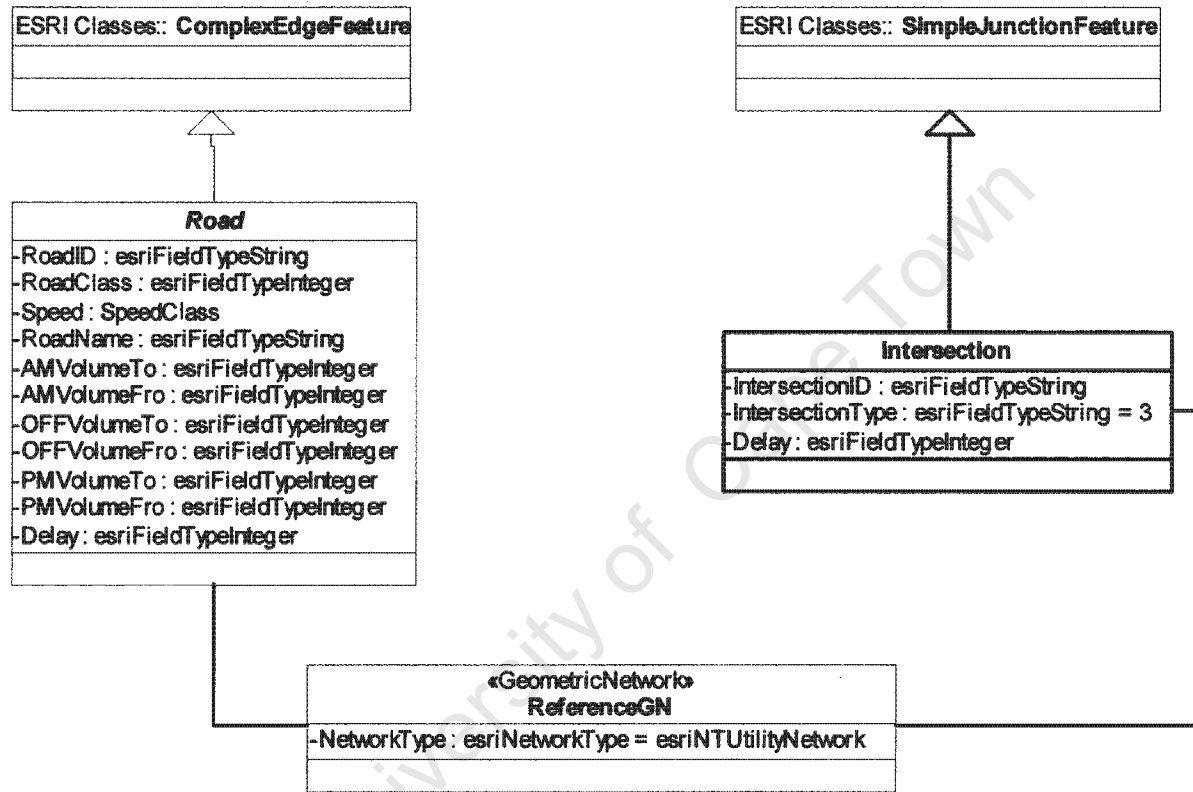


Figure 1: The public transport network schema in UML (Visio)

Appendix C

Calculating intersection delay

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Calculating delay at an unsignalled intersection

An unsignalled intersection is one where there are no traffic lights available. The formula used for calculating the delay at an unsignalled intersection is explained below (Papacostas et al 1993).

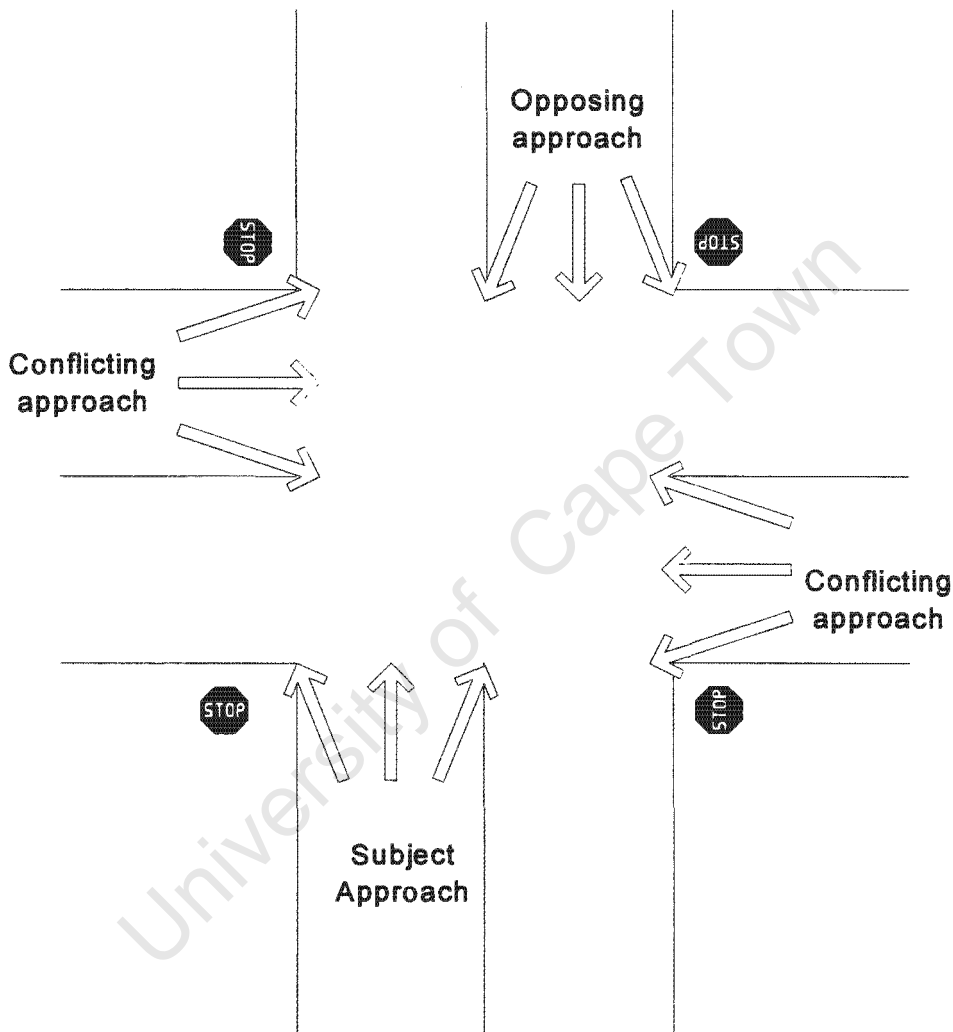


Figure 1: Delay at a four-way stop controlled intersection

The subject approach is the approach of interest. If, for example, the public transport vehicle is travelling from the south to the north and therefore has to pass through the intersection shown in Figure 1 above. The subject approach is therefore the southbound approach. The delay equation can be derived as follows:

The capacity of the subject approach (C) can be calculated as follows.

$$C = 1000V^S\% + 700V^O\% + 200L^S - 100L^O - 300LT^O\% + 200RT^O\% - 300LT^C\% + 300RT^C\%$$

Equation 1: The equation for calculating the capacity

Where

C = the capacity of the subject approach in vehicles per hour

$V^S\%$ = the proportion of the intersection volume on the subject approach

$V^O\%$ = the proportion of the intersection volume on the opposing approach

L^S = the number of lanes on the subject approach

L^O = the number of lanes on the opposing approach

$LT^O\%$ = proportion of volume on the opposing approach turning left

$RT^O\%$ = the proportion of the volume on the opposing approach

$LT^C\%$ = proportion of the volume on the conflicting approaches turning left

$RT^C\%$ = the proportion of the volume on the conflicting approaches turning right

The average delay on the subject approach is given by:

$$D = e^{3.8(V/C)}$$

where:

D = the delay on subject approach in seconds per vehicle

V = volume on subject approach

C = capacity of subject approach calculated from in Equation 1 above

The same equation can be applied to T-intersections and two-way intersections.

On the brighter side of things, the user does not need to know any of the equations because there are inside the program. The user just inputs the information required in the module shown in Figure 2 below and the delay is automatically calculated.

Calculate delay at an unsignalised intersections

For EastBound Traffic							
Left Turn Traffic	<input type="text"/>	Through Traffic	<input type="text"/>	Right Turn Traffic	<input type="text"/>	Click for total	<input type="text"/>
For WestBound Traffic							
Left Turn Traffic	<input type="text"/>	Through Traffic	<input type="text"/>	Right Turn Traffic	<input type="text"/>	Click for total	<input type="text"/>
For NorthBound Traffic							
Left Turn Traffic	<input type="text"/>	Through Traffic	<input type="text"/>	Right Turn Traffic	<input type="text"/>	Click for total	<input type="text"/>
For SouthBound Traffic							
Left Turn Traffic	<input type="text"/>	Through Traffic	<input type="text"/>	Right Turn Traffic	<input type="text"/>	Click for total	<input type="text"/>

Select Subject Approach

East Bound
 West Bound
 North Bound
 South Bound

Vs Lto Lo Ls

Vo Ltc Click to calculate capacity Capacity

Rtc Rto Click to calculate delay Delay

Click to close this window Select intersection to update

Figure 2: Showing the form designed in ArcMap that enables the calculation of the delay at an unsignalised intersection, which can then be used as a weight in Network Analysis

The form shown in Figure 2 above can be accessed by opening the FPrototypeMap.mxd in ArcMap, going to the Network Analysis Menu and clicking on To use the form, the following procedure is followed:

- Input the left turn, right turn and through traffic volume values for each approach and then click the “Click for Total” button for the program to calculate a total.
- Select a subject approach and all the other parameters following that are automatically calculated and the output values are displayed in the text boxes assigned to each parameter.

- Click on the “Click to calculate capacity” button and the capacity is shown in the text box next to this button.
- Click the “Click to calculate delay” button and the delay is shown in the text box next to this button.
- Lastly, click on the “Select intersection to update” button to open the attribute table of intersections and then appends the calculated delay (Please note that this can only be possible when in the editing mode of ArcMap).

Ass can be deduced from the delay equation above and the form shown in Figure 2 above, calculating intersection delay requires more detailed traffic volume information.

Calculating delay at a signalised intersection

The calculations in this research are based on the 1985 Highway Capacity Manual. The delay is the total time vehicles are stopped in an intersection approach during a specified time period divided by the number of vehicles departing from the approach in the same time (Edwards 1992 and Thanuesuen 2002).

The delay is calculated as follows:

$$d = pf * (d_1 + d_2)$$

$$d_1 = 0.38 * C \frac{[1 - g/C]^2}{[1 - (g/c)(X)]}$$

$$d_2 = 173 * X^2 [(X - 1) + \sqrt{(X - 1)^2 + (16 * X / c)}]$$

Where:

pf = progression factor

C = total cycle length (in seconds)

g = effective green time on the approach (in seconds)

X = v/c = the ratio for the approach

v = flow rate for approach (passenger vehicles per hour)

c = capacity of approach (passenger vehicles per hour)

d = average stopped delay in seconds per vehicle

Estimates:

- The progression factor is usually estimated from 1.85 (for dense arrivals at the beginning of a predefined signal red phase) to 0.40 (for dense arrivals at the beginning of the green phase of a fully actuated signal).
- For random arrival, the progression factor = 1.00
- The total cycle length, C , varies from 60 to 90 seconds
- The effective green time, g , varies from 4 to 6 seconds

The following form was developed in the software to enable the calculation of this delay:

The screenshot shows a software window titled "Signalised Intersection Delay" with a close button (X) in the top right corner. The window is divided into two main sections: "Enter the parameters" and "Calculations".

Enter the parameters: This section contains four input fields labeled v , g , C , and c .

Calculations: This section contains several buttons and output fields:

- A button labeled "Calculate X" next to an output field "X =".
- A button labeled "Calculate d1" next to an output field "d1 =".
- A button labeled "Calculate d2" next to an output field "d2 =".
- An input field labeled "Enter PF" next to an output field "d =".
- A large button labeled "Calculate average stopped delay" next to the "d =" output field.

At the bottom of the window, there are two buttons: "Click to close this window" and "Select intersection to update".

Figure 3: Showing the form in ArcMap for calculating average stopped delay at a signalised intersection

The procedure is as follows:

- Input the v , g , C and c values.

- ❑ Click on 'Calculate X' and the resulting value will be output on the text box next to the button.
- ❑ Click on 'Calculate d1' and the resulting value will be output on the text box next to the button.
- ❑ Click on 'Calculate d2' and the resulting value will be output on the text box next to the button.
- ❑ Enter the progression factor and click on 'Calculate average stopped delay' to calculate the delay.
- ❑ Select the intersection to update and enter the delay value in the delay field of the attribute table.

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Appendix D
Software Manual

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This manual has been divided into two sections. The first section is for the Visual Basic application and the second section for ArcMap. Please note that no editing takes place in the Visual Basic application. All the editing and other advanced queries like Network Analysis can only be performed in ArcMap.

To load the Visual Basic application, run the set-up as instructed in the Set Up document enclosed with the CD.

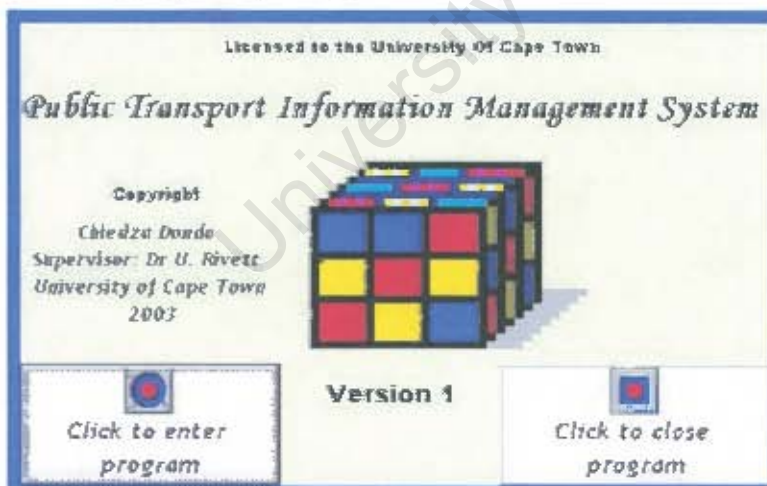
1. Opening the program

After setting up the application, the user opens the program the double-clicking the

 Prototype Prototype.exe .

Section One

- ❑ From the dialog Welcome window that appears, click on the button labelled "Click to enter program" (see Figure 1 below):



- ❑ The main window will appear on screen, from which the user can choose the task they want to perform.
- ❑ From either the menu bar or by clicking on buttons on the toolbar, the user can choose to do:

- Passenger analysis
- Find the shortest path
- Ride check analysis
- Map-based Queries


NB: By placing the mouse on each of the toolbar, the user gets information on what each of the toolbars represent. The analyses are discussed below but most of the steps are very self-explanatory and straightforward to follow.


2. Passenger analysis


- After selecting passenger analysis, a window will open up, asking you to select whether you want to view information on 'one specific route for different times of day', 'different times of day for all routes' or 'by stop for different times of day'.

Option 1: After selecting 'one specific route for different times of day'

- You get a window, showing the route on map with the following tools. These tools will be available for most analysis and their functions are as follows, starting from the left:

Zoom In : If you click on this button and drag a rectangle on the map on the area of interest, the map will zoom in on the area.

Pan : For moving the map to focus on the area of interest.

Identify : Clicking on this button and clicking on a feature on the map will open a window showing information on the feature.

Zoom to full extent : Zooming in to the full extent of the map.

- You can add the road as a base layer or remove it if you do not need to print a map (but first ensure that it is selected in the table of contents).
- You can choose not to display a layer but unchecking the box next to it in the Table of Contents

- You can print the map; view a report on the route or the buses for the route by just clicking on each of the buttons labelled.

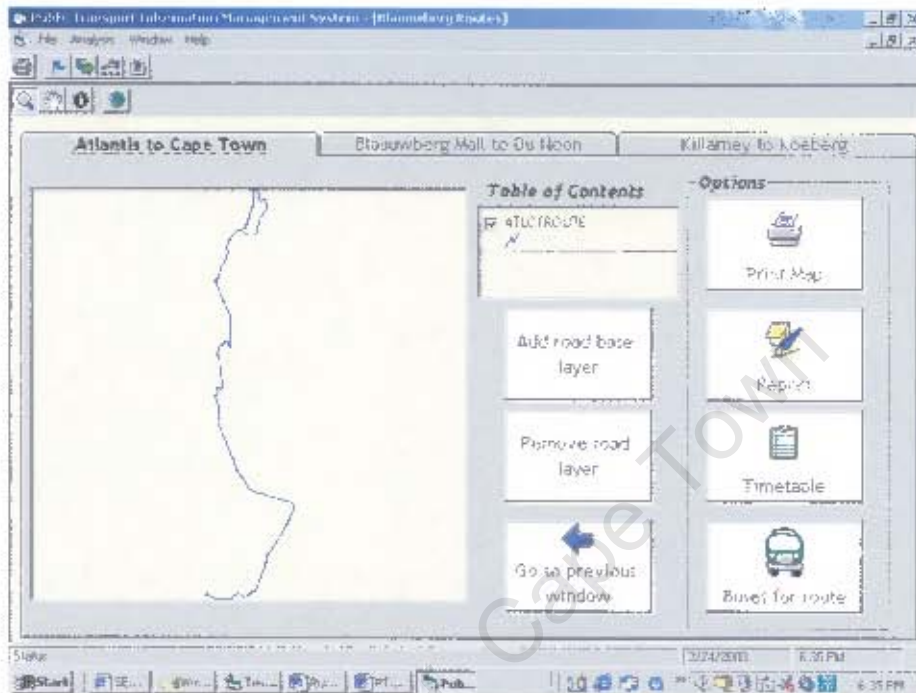


Figure 1: Form for the Atlantis to Cape Town route

Option 2: After selecting 'Different times of day for all routes'

- A form is displayed, with tabs for the different times of day.
- For each of the times of day you select, you can either view or print a report or a graph of all the routes for that time of day.
- Below is an example of the graph you can print

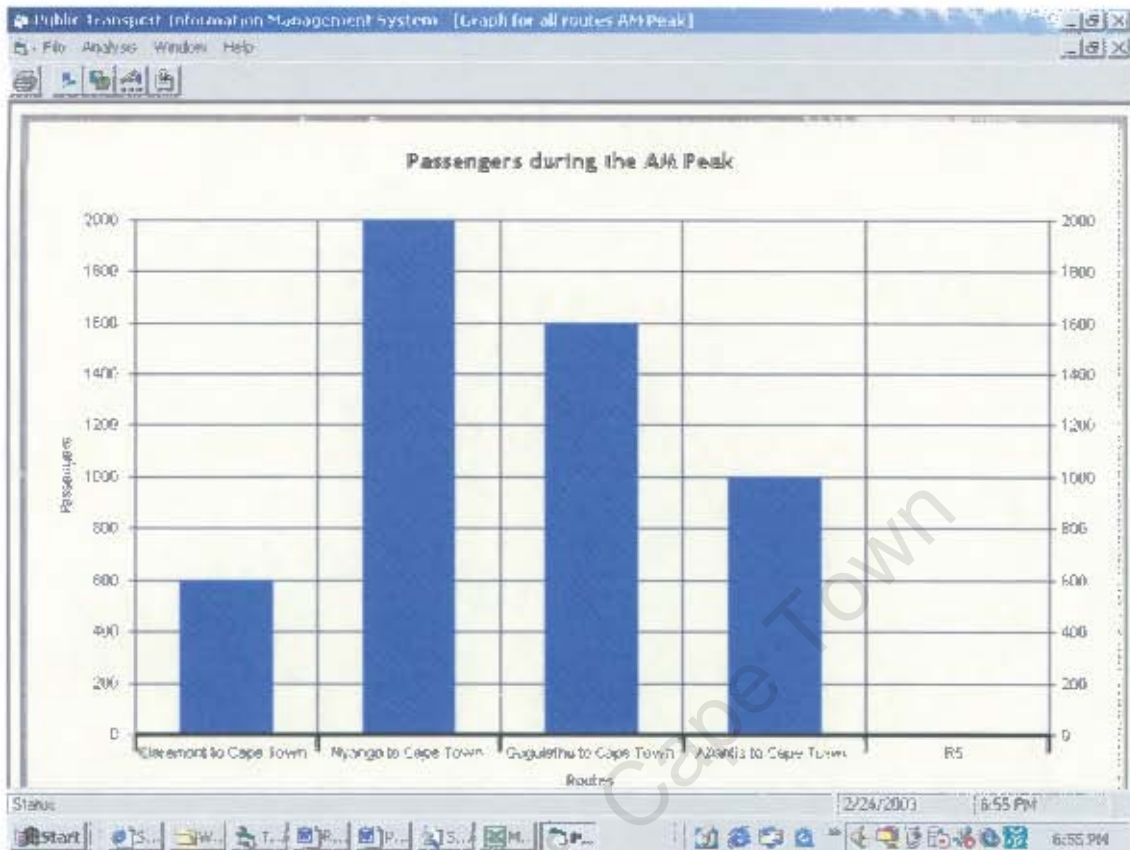


Figure 2: Graph of the number of passengers for all routes during the AM Peak

2. Option 3: After selecting 'By stop for different times of day'

- A form is displayed showing a layer of stops.
- You can create graphs by selecting the fields you want to use for the graph in the list box provided.
- You can select multiple fields by holding the 'shift' or 'ctrl' button on the keyboard while selecting the fields.
- The items in the list box are explained below:

PassAAM- passengers getting off the bus at that stop during the AM Peak

PassBAM- passengers boarding the bus at that stop during the AM Peak (and so on for the other two peaks which are the PM Peak or the OFF Peak).

- A map containing the created graphs can be printed.

3. Find shortest path

- If you choose this analysis, a form opens up with a road layer and some command buttons.
- In this form, you can choose to use the mouse as either a zoom tool or to click the start and end points of the proposed route on the map.
- After selecting, 'click point', place two points on the map where you want the route to start and end.
- You can change the size of the points by sliding the bar.
- Click 'Find Path and display it'.
- You can then select to label the map and print it or export it to an image file.

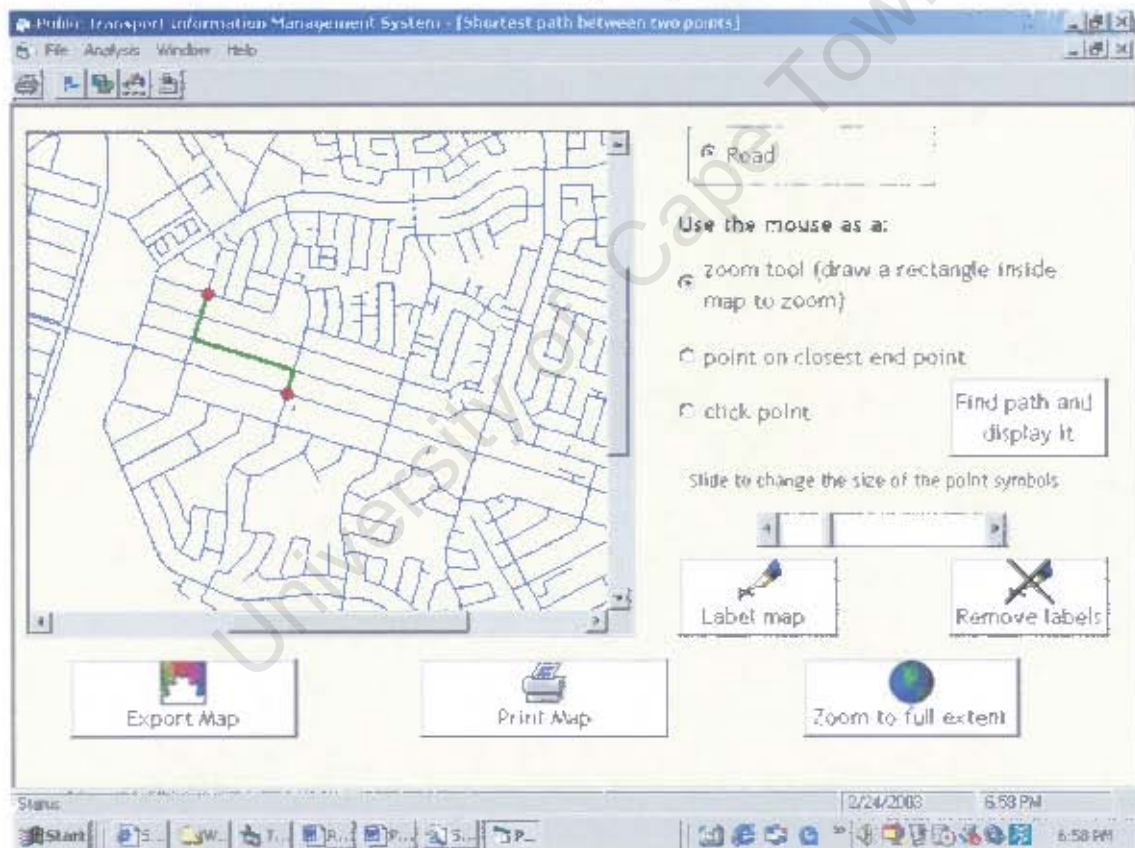


Figure 3: The shortest path analysis window

4. Ride check analysis

Select the Ride check analysis from the Main Menu or by clicking on the button on the toolbar. The user can choose to view the number of passengers 'graphically per stop on a map' or ' graphically per section of route on a map'.

Option 1: Graphically per stop on map

- You can view and print a report of all stops by clicking on "View reports"
- Using the Identify tool, you can click on it and then click on any feature on the map to get information on that feature.
- You can create a graph for the number of passengers boarding and getting off at each stop by selecting PassB and PassA in the list box and then selecting the kind of graph you want to create (whether pie chart or a bar chart).
- The map containing the graph can then be printed.

Option 2: Graphically per section of route on a map (to display the number of passengers who traveled along each section during the ride check survey and print out a map):

- Click on the 'Display by varying width' button to display the number of people who were travelling along each section of the route during the survey.
- Click on label map to label the map according to the number of passengers who were travelling along that route during the survey.
- Using the Identify tool, you can click on it and then click on any feature on the map to get information on that feature.

5. Map-based Queries

The purpose of map-based queries is for selecting features on a map according to certain criterion one wants to set and then print or export the output and print it out.

- If you select map-based queries, a form will display showing the layers on the map. The layers on the map are the roads, the populations, the stops and the routes. The tools available on this window and their functions are explained below.



- You can change the order of the layers by selecting a layer and dragging it to another place in the box labelled 'Table of Contents'.
- If you click on map properties , or if you go to the Menu, View- Map properties, you get a dialog box (see Figure 4 below). From this box, you are able to:
 - Add more layers to the map
 - Select map units for the map
 - Set the background colour and border for the map.



Figure 4: Map properties dialog box

- If you click on the find button  or if you go to the Main Menu, click on edit then Find, the dialog box shown in Figure 5 below opens up.

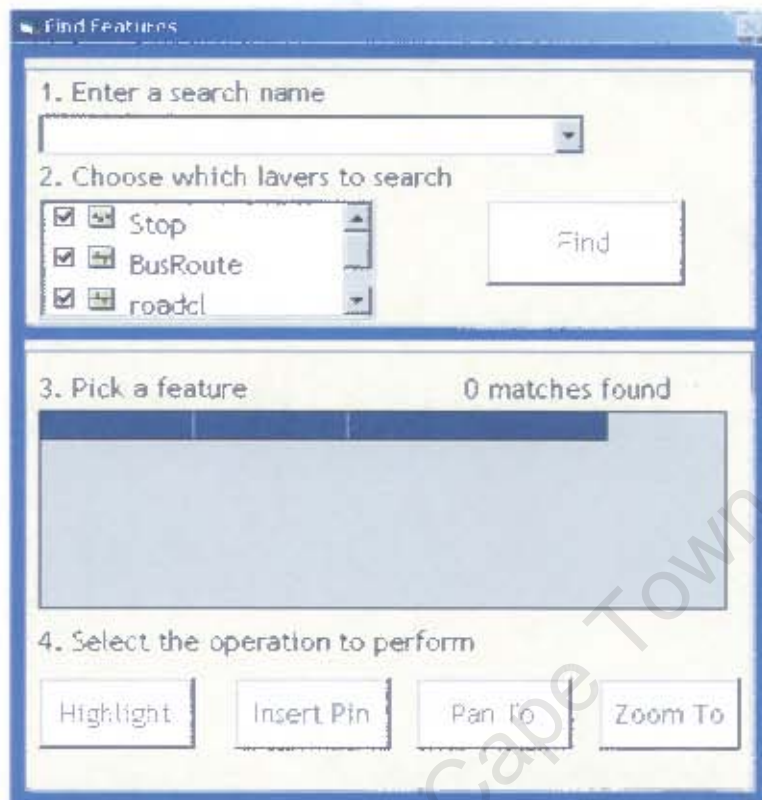


Figure 5: The find dialogue box

From this dialogue box:

- You first check the box next to the layer you want to find features from
- You then enter an attribute value in the text box provided.
- After that you click the find button.
- If more than one feature are found, pick a feature from the list.
- Lastly, chose whether you want to highlight the feature, zoom to it, or insert a pin.

The find button is quite difficult to work with because you need to know, in advance, the values you are looking for, otherwise it is advisable to use the identify tool (explained below).

- The next set of tools are zoom tools (see Figure 6 below).



Figure 6: Zoom tools



- The identify button can be used when one wants to retrieve information on any feature on the map. Click on the identify button  and then click on any feature of interest on the map. A dialog box opens up showing all the attributes of that feature.



Figure 7: Dialog box showing the identify results

- The spatial select button  is used when one wants to select features from the map using a shape, for example a line, a rectangle or a circle.
- After clicking on the spatial select button, a dialog box appears, where one selects the selection they want to perform (see Figure 8 below).
- For example, in Figure 8 below, a rectangle will be drawn in the map at a selected point so that all stops that will be falling within the rectangle are selected.

- Unless you clear the first selection, all further selections performed will add on to the one already made.

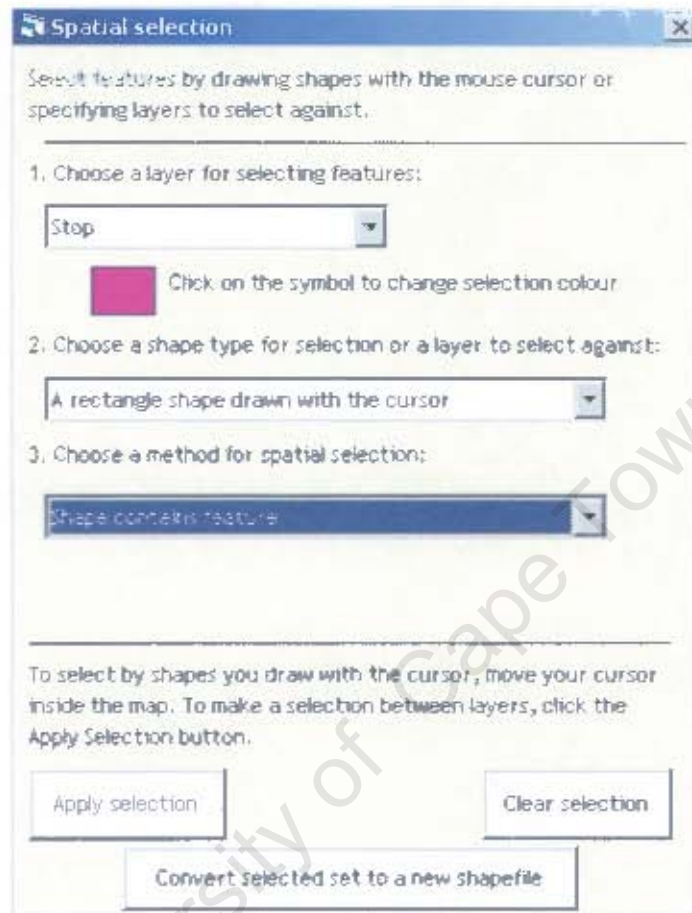


Figure 8: Spatial select dialog box

1. Clicking on Layers, Legend Editor, will open a dialog box from where you can:
 - Choose how you want to label a layer on the map (you first need to make sure that the layer is selected in the Table of contents).
 - Change the display colour of a layer.
 - You can display the attributes using classes.
2. Click on 'Create Map Layout' to create and print Map Layouts.
 - A layout window will open up.
 - You can add each of the elements on the map by selecting it and drawing on the map.

- After adding the components, you can click on 'Preview' to see what the map looks like.
 - If you are not satisfied, you can click on 'Compose' and start creating it again.
 - After you are done creating the map, click on 'Print Now'
3. You can check on the Map Tip checkbox at the bottom of the map to select the field in a shapefile from which the tips are coming from.
 4. If you select, StopName, for example, if you place the mouse pointer on any stop on the map, the StopName will be displayed.

ArcMap Section 2

This instructions for this section of the analysis are not exhaustive because the assumption is that if you have ArcInfo on your computer, you probably also have a copy of the user manual. The Version of ArcInfo required is 8.1 or higher. Load the CD and double click on 'Iprototype.Map'. The type of analysis that can be performed in this system have been divided into the following categories:

- Ridership analysis
- Network analysis
- Accessibility analysis
- Other attribute queries

These analyses will be discussed in the order provided above with a final discussion on creating a map and printing the output and the editing option.


2.1. Ridership analysis

These analyses are performed when it is required to find out the approximate number of people (or passengers) in this case who travel by bus along a certain route. In this application, statistics are only available for one particular bus route.

2.1.1 To display the number of passengers along each section of the route

- Note that this has been performed already by displaying the numbers using lines of different widths, that is a thicker line representing more people. A map of this

information can be created and printed out when required (see Section for creating a map).

- If the Table of Contents is not visible, click on the open Table of contents button  to open it.
- Tick on the on the box next to trip path events in the Table of Contents to open the layer.
- Double-click on the layer in the table of contents to open the Layer Properties box.
- Click on the symbology tab. Under Show, select Quantities. graduated symbols (as shown in figure below):

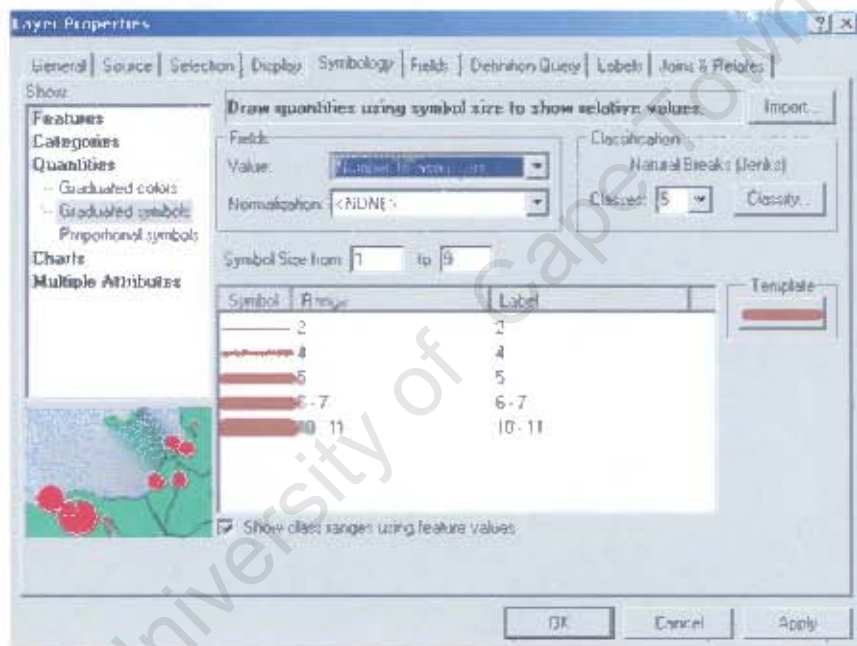


Figure 9: Displaying number of people per route using lines with varying width sizes

- You can display click on template to get a box (like the one in figure below) from where you can select the colour and the style you require. Click OK.

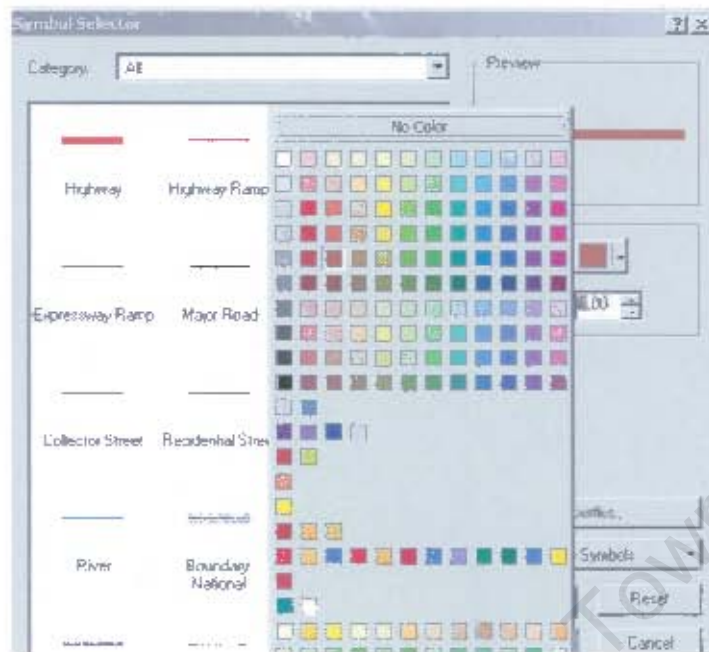


Figure 10: Selecting the colour and line style for displaying passengers

- You will return to the layer properties box, where you will click on apply and then OK.
- Instead of using lines of different widths, different colours can be used by clicking on the graduated colours option instead of the graduated symbol.

2.1.2. To create a report with a sum of people along each section of the route to get an overall value for the whole route

- Go to the Main Menu, click on Analysis and open the Ridership analysis form.
- Click on the “create route for the whole route” button. Please be patient, it takes a while for the report properties dialog box to open.

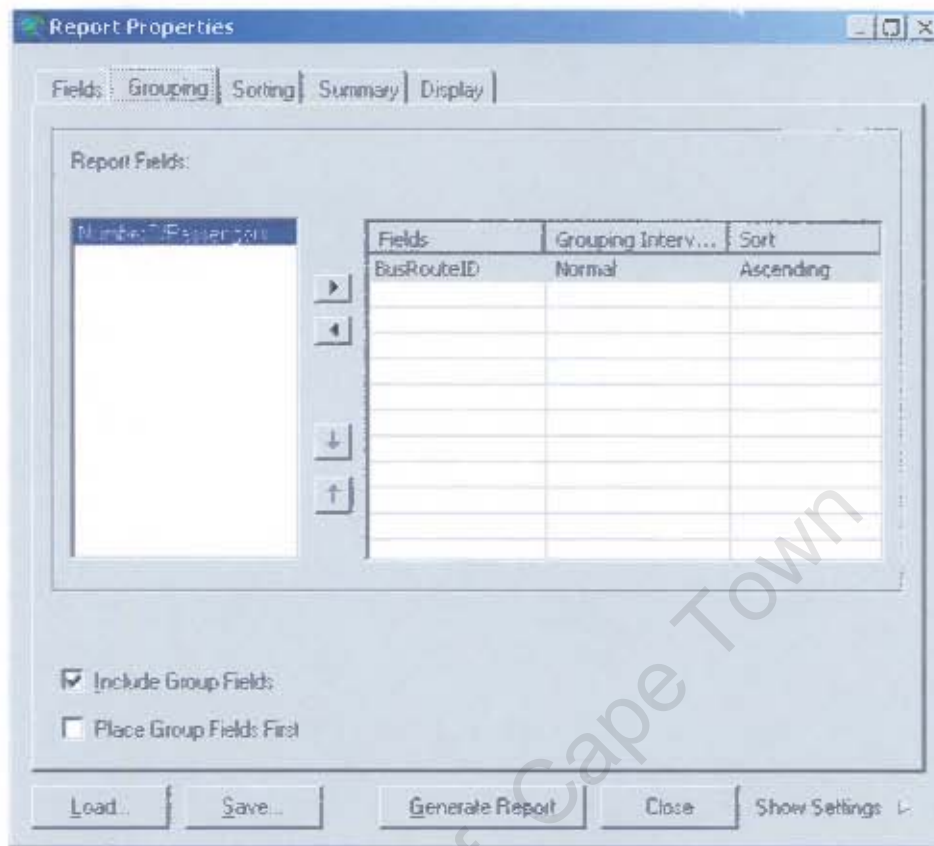


Figure 11: Report properties dialog box

- In the Report Properties dialog box, set the following settings:
 - Set layer table to trip path layer
 - From the “available fields” box, select the NumberOfPassengers and BusRoute fields and send them to the “Reported Fields” box.
 - Go to grouping, and add BusRoute field.
 - On Summary, in the available sections, select end of group BusRoute.
 - In Numerical Fields, tick in the Sum box.
 - In the Display tab, you can set the display colours and other options.
- You can save the report.

2.1.3. To display the number of people boarding and alighting at each bus stop

- Double click on the Stop layer in the Table of Contents to open the layer properties window.
- Click on the Symbology tab and select charts from the Show box.

- Select the “NumberofPassengersAlighting” and “NumberofPassengersBoarding” fields and select the type of chart you require and the colours.
- Click OK.

2.2.Network Analysis

This is an important component of every public transport management system. It assists in ascertaining the shortest path between any two points or bus stops or stations. The shortest path can be based on various factors. In this program, one can calculate the shortest path based on:

The volume of traffic along a section of the road

This volume has been divided into morning (am peak), afternoon (off peak) and evening (pm peak). This means that ideally, one can select a different route for different peaks of the day based on the volume of traffic in that route at that particular time.

The delay at intersections

The delays have been pre-calculated for the intersections concerned and for a thorough discussion on how to calculate this delay, please see the editing section of this manual. A module was developed in this application for calculating this delay. It is based on the volume of traffic in the different sections of the road meeting at an intersection.

The time taken by a vehicle to traverse a section of the road

This is basically derived from the length of that road section and the maximum allowable speed for vehicles travelling on that section of the road. The time taken is then calculated as follows:

$$\text{Time} = \frac{\text{Distance(m)}}{\text{Speed(m/s)}}$$

To perform the analysis, the following procedure is followed:

- Go to the Network analysis bar and click on Analysis, then Options.
- You get a dialog box like the one indicated in Figure 8 below.

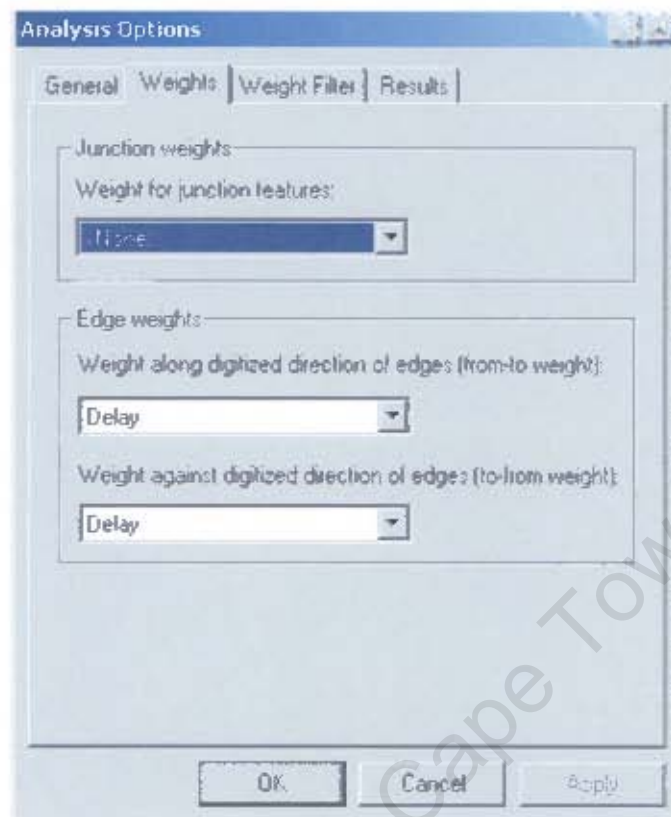




Figure 12: Setting network options

- On general tab, set it for select on all features.
- On the weights tab, select the weights you want to use, in figure 8 above, the weights being used are edge weights and this is the delay (which is the time taken to traverse a section of the road discussed in Section 2.1 above).
- On the Weight Filter tab, set so that features with weights of "0" are not included, by typing in "0" in the Weight Range box and ticking the Not box.
- Still on the Weight Filter tab, on the Edge Weight Filter, for the From_To Weight and To_From Weight, specify the same weight. This just means that it takes the same amount of time to traverse in both directions of the road.
- On the results tab, you can select whether you want it to display the results as drawings or whether it should select the features.
- Click OK.
- Go back to the network menu, click on the add edge flag tool  and place the flags on the map to where you want the route to start or end at. Please note that the flags

should be exactly on a line representing the road otherwise the analysis would not provide any results.

- From the “Trace Task” dropdown menu, select the “Find Path” option.
- Click the Solve button  and the path will be drawn in a different colour.
- If you check on the status bar it should display the total cost of the route.
- You can go to analysis, clear flags or clear results to remove the flags and the results respectively.

You can then repeat the analysis, varying the weights being used in each case.

2.3. Accessibility analysis

These are done when it is required to analyse how accessible the bus stops and stations are to the people living in the area. For example, if you want to find the number of people living within 100 metres of a certain stop.

- Check the census layer in the Table of Contents to see the layer in the map view.
- On the menu bar, click on analysis and open the accessibility menu item (see Figure 9 below).

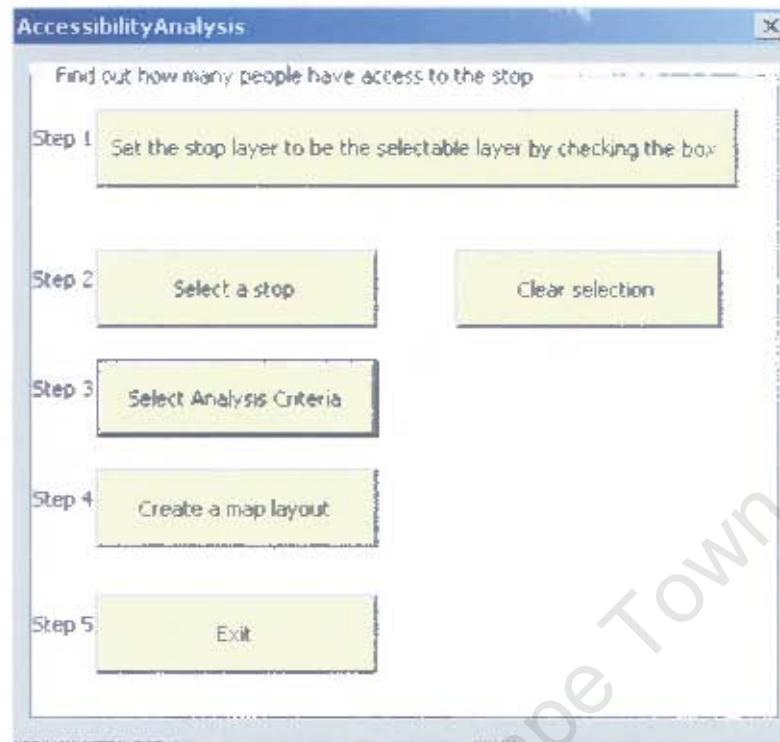



Figure 9: Accessibility analysis form

- Set stop to be the selectable layer by checking in the box beside the stop layer.
- Click on "select stop" to select the required stop.
- Click on the selection criteria button to specify the following parameters.
- Say you want to select features from the population layer, which are within 100 metres of the selected stop.
- Click OK.
- From the selected features, you can open the attribute table button  to get the number of people in that area.

2.4 Other attribute queries

GIS is a very powerful tool in analysis so more analysis than are indicated above are possible. The following section just gives examples of other analysis possible.

2.4.1. To find out which buses are serving a certain route and the drivers of the buses

- Click on the select tool. Select the route on which you want to make an enquiry.
- Click on the attribute button on the Editor Toolbar.
- Double-click on the bus to get the number of the bus and other bus attributes.
- Click on employee to get the name of the driver.
- By clicking on the hyperlink tool and clicking on a route, an image of the bus can be viewed.

2.5. Editing

NB: You need a password for this section so if you find yourself without a password; you are not required to edit this application.

Appendix E

Sample Questionnaire

University of Cape Town

