A computerised decision support system for the implementation of strategic logistics management optimisation principles in the planning and operation of integrated urban public transport.

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DECLARATION

I, the undersigned, hereby declare that the work contained in this dissertation is my own original work and has not previously, in its entirety or in part, been submitted at any university for a degree.

W.R. Duff-Riddell

SYNOPSIS

Public and private transport system planning and operation have tended to be fragmented functions. In particular, public transport is often planned and operated independently of the "private" transport system. South African government policy now requires that comprehensive, strategic transport plans be prepared by metropolitan transport authorities. These plans are expected to conform to national strategic objectives as well as including local current and long-term objectives. This planning is required in the environment of a multi-modal, multi-operator, public-private partnership scenario that is new for most of the role players. The lack of experience is accompanied by a lack of any existing model for dealing with this scenario. This dissertation describes such a model. The model is based on the principles of strategic logistics management commonly employed in commerce and industry, including service-oriented industries. The modelling process is thus based on achieving a combination of customer service and long-term objectives.

The model comprises a number of separate components and steps:

- A transport network model (Emme/2).
  - A multi-class, generalised-cost assignment of private and public transport demand onto a network, modified to be modeless to the public transport users, is performed. This assignment allows for the imposition of generalised-cost reflecting urban-planning objectives in addition to more conventional costs such as travel cost. In this assignment, the interaction of public and private transport is accounted for and results in an associated modal choice.
  - A series of single-class generalised-cost assignments is then used to "focus" public transport demand to create corridors of demand adequate to justify public transport routes. This process can be enhanced to develop a design promoting switching from private to public transport. It also allows for multi-period route design.
  - The results of this modelling process are output to a text file and then subject to the processes described below. The results of these processes are then input into the network model where a standard transit assignment is performed and used to modify the proposed lines and update the network design data with respect to boardings and alightings at nodes. This information is used to design fixed infrastructure.

- A Microsoft Access database and route extraction program.
    - The network model data is drawn into the database where it is subject to a route extraction program that converts the assignment results from the network model into a set of mode specific potential public transport route definitions. These route definitions are based on paths of maximum demand. The extraction process is controlled by parameters specified by the planner, such as minimum route lengths and the demand level for various categories of service.
    - After route extraction, vehicle allocation, and transit assignment, the database provides details of the boardings and alightings and number and details of transit lines using each node and link in the network. This data is used to design fixed infrastructure.
- A Microsoft Excel spreadsheet vehicle operating cost model.
    - For each vehicle type, the operating cost given the anticipated vehicle mileage and operating speed is determined. This is used to guide the choice of vehicles for different routes.
- A Lingo goal-programming model.
    - The potential routes and the available or potential fleet are subjected to a goal-programme in which the optimum choice of vehicle allocation is determined. The allocation parameters can be controlled by the planner. These parameters may include costs, energy, fuel consumption, and vehicle and route limitations amongst others. Multi-period design is included in the modelling process so that the optimum design may be for the operating period, daily, or weekly cycle.

The modelling process provides two main outputs:

- A set of fully described and costed transit lines in terms of both routing and vehicle allocation. These transit line definitions can be output to the level of driver instructions if necessary.
- Details of the type and location of infrastructure to be provided on the network.

OPSOMMING

Openbare en private vervoerstelsel-beplanning en -bedryf is geneig om gefragmenteerde funksies te wees. Dit is veral waarneembaar in die openbare vervoerstelsels waarvan die beplanning en bedryf onafhanklik van die "private" vervoerstelsels plaasvind. Die beleid van die Suid-Afrikaanse regering vereis dat omvattende strategiese vervoerplanne deur die metropolitaanse vervoer owerhede voorberei word. Daar word van hierdie planne verwag om aan die nasionale strategiese doelwitte, asook die plaaslike bestaande en langtermyn doelwitte te voldoen. Hierdie beplanning word vereis deur 'n omgewing wat nuut is vir die meeste rolspelers en bestaan uit multi-modale, multi-operateur en openbare-private vennootskap scenario's. Die tekort aan ondervinding gaan gepaard met 'n tekort aan 'n bestaande model wat gebruik kan word om hierdie scenario's te hanteer. So 'n model word deur hierdie verhandeling beskryf. Die model is gebasseer op die beginsels van strategiese logistieke bestuur wat algemeen gebruik word in die handel en industrie, insluitende die diens-georïenteerde industrieë. Die modelleringsproses wil dus 'n kombinasie van diens aan kliënte en langtermyn doelwitte bereik.

Die model bestaan uit onderskeie komponente en stappe:

- 'n Vervoernetwerkmodel (Emme/2)
    - 'n Multi-klas, veralgemeende-koste toedeling van private en openbare vervoeraanvraag op 'n netwerk, aangepas om modusloos te wees vir die openbare vervoergebruiker, word uitgevoer. Hierdie toedeling laat nie net die heffing van meer konvensionele kostes, soos reiskoste toe nie, maar ook veralgemeende kostes wat staatsbeplanningsdoelwitte reflekteer. In hierdie opdrag word die interaksie van openbare- en private vervoer ondersoek waarvan die uiteinde 'n geassosieerde modale keuse is.
    - 'n Reeks enkelklas veralgemeende koste toedelings word dan gebruik om op openbare vervoeraanvraag te fokus en daardeur korridors van aanvraag, wat gepas is om openbare vervoerroetes te regverdig, te skep. Hierdie proses kan verfyn word om 'n plan te ontwikkel wat die verskuiwing van private vervoer na openbare vervoer sal bevorder. Dit laat ook die ontwerp van multi-periode roetes toe.
    - Die resultate van hierdie modelleringsproses word uitgevoer na 'n tekslêer en dan aan die prosesse, wat hier onder beskryf word, onderwerp. Die resultate van hierdie prosesse word dan ingevoer in die netwerkmodel waar 'n standaard publieke vervoertoedeling uitgevoer word. Dit word dan gebruik om die voorgestelde roetes te wysig en die netwerk

data, met betrekking tot die aantal persone wat op en af klim by nodes, op te dateer. Hierdie inligting word gebruik vir die ontwerp van infrastrukture.

- ‘n Microsoft Access databasis en roete-ontrekkingsprogram
  - Die netwerkmodel data word in die databasis ingetrek waar dit aan ‘n roete-ontrekkingsprogram onderwerp word. Hierdie program skakel die toedelingsresultate van die netwerkmodel om na 'n stel potensiële modus spesifieke openbare vervoerroete definisies. Hierdie roete definisies word gebasseer op paaie van maksimum aanvraag. Die ontrekkingsproses word deur parameters, soos minimum lengte van roetes en die vlak van aanvraag van verskeie kategorieë van diens, wat deur die beplanner gespesifiseer word, gekontroleer.
  - Na die ontrekking van roetes, voertuigtoekenning en vervoertoedeling, voorsien die databasis besonderhede van die aantal persone wat op en af klim asook die aantal en details van vervoerroete wat elke node en skakel in die netwerk gebruik. Hierdie data word gebruik om infrastrukture te ontwerp.
- 'n Microsoft Excel sigblad voertuig bedryfskoste model
  - Vir elke tipe voertuig word die bedryfskoste, volgens die verwagte afstand en spoed van die spesifieke voertuig, bepaal. Die resultate word gebruik om die keuse van voertuie vir verskillende roetes te bepaal.
- 'n Lingo doelprogrameringsmodel
  - Die potensiële roetes en die beskikbare of potensiële vloot word onderwerp aan 'n doelprogram waarin die optimum keuse van voertuigtoekenning bepaal word. Die toekenningsparameters kan deur die beplanner gekontroleer word. Die parameters kan onder andere kostes, energie, brandstofverbruik en voertuig- en roete beperkings, insluit. Multi-periode ontwerp is ingesluit in die modelleringsproses sodat die optimum ontwerp vir die bedryfsperiode, daaglikse of weeklikse siklusse, kan wees.

Die modelleringsproses lewer twee hoof uitkomste:

- 'n Stel volledig beskrywende en koste berekende vervoerroete wat, indien nodig, na die vlak van bestuurder instruksies, uitgevoer kan word.
- Details van die tipe en plek van infrastruktuur wat benodig word deur die netwerk.

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A NOTE ON SPELLING

This dissertation is written using British English spelling conventions. Some words may however, have alternative spellings arising out of common usage. (An example is capitalization – capitalisation: The former is the American and an allowed spelling in both the Oxford and Collins dictionaries. MS Word allows only the latter form for British English.) In these cases, the spelling used in the word processor spell checker has been used. Because some of the references are from American literature, titles and quotations are given with the original spelling. This may result in an apparent lack of consistency, especially where the British "s" is replaced with "z" in America; e.g. analyse – analyze. A similar problem arises with the use of single versus double letters such as "program," used in American English and "programme" in British English. The language change should usually be clear from the reference source given with the quotation.

CONTRIBUTION AND CONTEXT

The author believes that this work makes the following contributions to the field of transport and public transport planning:

1. An approach to modelling multi-modal public transport and private road transport concurrently on the same network so that the interactions and public transport mode choices can be evaluated. This is with particular reference to the South African Department of Transport "White Paper on National Transport Policy" of 1996.
2. A method for achieving a compromise between the free assignment of public transport trips on a multi-modal network and a feasible public transport service. This method uses a sustainable-frequency penalty to focus trips onto routes so that sufficient demand exists to justify a service.
3. An empirical technique for converting the link demand arising from the network modelling process into a set of potential public transport lines that maximise vehicle utilisation within the framework of the demand pattern. This process also provides information for the planning of fixed infrastructure.
4. A model for assigning the available resources to the potential routes to minimise total cost and / or a variety of other, possibly conflicting objectives.

The network model techniques have been developed using Emme/2, whilst the bulk of the other decision support system processes are developed using Microsoft Office 97. The relatively inexpensive operations research software, Lingo has been used for the resource allocation models. The result is that there is very little expenditure on new software required in implementing the proposals. However, the decision support system is such that none of the named software is crucial to the implementation of the concepts although migration of the route extraction process to an alternative programming language might require some effort.

The entire process incorporates the principles of strategic logistic management, focusing on achieving sustainability of the entire business through the satisfaction of customer service objectives. This, in turn, is based on the requirement that all components of the business must be seen as a whole and not in their parts.

The contribution, whilst applicable to transport planning and public transport planning anywhere, should be seen in the context of the South African situation at the time of writing. The South African government has placed a high priority on public transport and on the concept of customer service whilst at the same time, initiating a system of tendered public transport services to be provided by a diverse range of operators under the management of the local transport authority.

The work presented here offers a management approach for use by the local authority in implementing the government policies as well as techniques for designing and operating the public transport routes using existing models, data and skills.

GLOSSARY OF ABBREVIATIONS AND OTHER TERMINOLOGY

This glossary of abbreviations is presented here, rather than as an appendix, because some of the abbreviations and terms appear in the Table of Contents.

CD	—	Compact Disc
DSS	—	Decision support system
EDI	—	Electronic data interchange
MS	—	Microsoft
ODBC	—	Open Database Connectivity
OLE	—	Object linking and embedding
OR	—	Operations Research (Except where used as a logical operator.)
PTB	—	Public transport business
RP	—	Revealed preference
SLM	—	Strategic logistics management
SP	—	Stated preference

Transit — Used interchangeably with **Public Transport**

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1 INTRODUCTION

In many facets of life, the fundamental problems remain much the same from century to century even though each generation believes the problem to be new or to have reached critical proportions. This is as true of transport as of anything else. For example, in 45 BC Julius Caesar introduced legislation to control congestion in Rome (Toynbee, 1970.) However, whilst the fundamental problems remain, technical developments alter the form of both the problem and the solution. Each new generation has to re-examine the problems and find new or modified solutions. Of course, the solutions are not always that new either. Public transport is usually presented as one of the important tools for alleviating some of the current transport problems. However, public transport features in Greek mythology, the ferry across the Styx was a fare paying form of public transport and modern urban public transport forms have been in existence for about 400 years (Vuchic 1981 pg. 11.)

Over the last century, the transport problem has taken on new dimensions. The number of cars, trucks, and buses in use worldwide, has grown from a negligible number to an estimated 725 million. The number continues to grow, with current estimates of over 1 billion such vehicles being in use in the year 2025 (SDIS 2000.) The car offers many advantages as a mode of transport; it is not however, without its problems. These problems take three forms (Steg 1995.):

- Environmental
  - The emission of toxic and harmful substances with impacts such as global warming, smog, and acid rain.
  - The use of scarce resources.
  - The production of solid waste.
  - The distortion and fragmentation of natural areas.
- Social
  - Affects the quality of urban life because of:
    - Space occupation, noise, and odour.
  - Traffic accidents
  - Mobility of emergency services due to congestion.
- Economic
  - Accessibility to economically important destinations is threatened by congestion.
  - Motorists transfer cost of negative effects to society as a whole.
  - Dependence on imported oil. (SDIS 2000.)

Given these problems, whilst there can be no question that motor vehicles have brought enormous social and economic benefits, there is also a need to provide and promote an effective alternative to private transport. These alternatives may include telecommuting, various forms of urban and social engineering and of course, public transport. In many countries, public transport is perceived as the only realistic alternative to private transport for the majority for, amongst other reasons, the strategic importance of a functional public transport system in an emergency.

Establishing an effective alternative to private transport is not a purely technical matter, but involves a wide variety of inputs, ranging from political purpose, carefully structured marketing and extensive management skills, through to the purely technical design of efficient alternatives. The technical design of public transport systems is not a trivial matter and is the subject of extensive research. There is however, a need to take more cognisance of the other inputs required in the design and operation of an effective alternative to private transport.

The realisation that this is the case is certainly not new and there is a considerable body of literature, extending at least back to the late 1960's, in which the social aspects of public transport are examined. In the 1970's and 1980's, Vuchic et al (1978 & 1981) and Barnes (1989) were well aware of and documented the importance of customer service in transport but this seems to have taken second place to the more technical issues. Since then, fields of research such as transport psychology have developed independently of the applied mathematics and engineering aspects of transport planning. This independent development seems to have reached a stage at which there is a strong interest in reassessing the technical design process. In this respect, there has recently been a strong movement in many countries, towards strategic planning and customer service oriented operations that are perceived to be at least as important as technical efficiency. Examples of this trend are to be found in the USA, Transportation Research Board TCRP Reports of 1999, and the South African DoT White Paper of 1996.

Given the foregoing, the author does not claim to have identified a new problem but rather to have developed a new approach to public transport planning. This new approach is in terms of current thinking and tools, particularly with respect to the situation in South Africa as outlined in the next section.

1.1 CONTRIBUTION AND CONTEXT

The author believes that this work makes the following contributions to the field of transport and public transport planning:

1. An approach to modelling multi-modal public transport and private road transport concurrently on the same network so that the interactions and public transport mode choices can be evaluated in conjunction with urban planning objectives.
2. A method for achieving a compromise between the free assignment of public transport trips on a multi-modal network and a feasible public transport service. This method uses a sustainable-frequency penalty to focus trips onto routes so that sufficient demand exists to justify a service. This technique can be applied using any network-modelling package.
3. An empirical technique for converting the link demand arising from the network modelling process into a set of potential public transport lines that maximise vehicle utilisation within the framework of the demand pattern. This process also provides information for the planning of fixed infrastructure.
4. A means of assigning the available resources to the potential routes to minimise total cost and / or meet a variety of other possible objectives.

The network modelling techniques have been developed using Emme/2. The decision support system database and user interface are developed using Microsoft Office 97 whilst Lingo (LINDO 1999) has been used to handle the resource allocation processes. In each case, alternative software could be employed with little modification in the process. The result is that there is very little expenditure on new software required in implementing the proposals.

The process incorporates the strategic logistic management principles, focusing on achieving sustainability of the entire business through the satisfaction of customer service objectives. This, in turn, is based on the requirement that all components of the business must be seen as a whole and not in their parts.

The contribution, whilst applicable to transport planning and public transport planning anywhere, should be seen in the context of the South African situation at the time of writing. The South African government has placed a high priority on public transport and on the concept of customer service. At the same time, it has initiated a system of tendered public transport services to be provided by a diverse range of private operators and managed by the local transport authority. These requirements are imposed under constrained economic conditions and in conjunction with other developmental programmes, such as the mini-bus taxi re-capitalisation scheme. This dissertation proposes techniques for designing and operating the public transport network under these conditions, using existing models, data, and skills, at minimum expense.

1.2 MOTIVATION FOR RESEARCH PROJECT

There have been four primary motivations for embarking on this project. The first of these is a personal perception that transport planners give public transport inadequate attention, focusing rather on private transport, treating the two as essentially separate entities. The result is that public transport often appears fragmented in its planning and operation and this shows in the poor services offered. This perception exists in an environment where, whilst there is constant reference to what are termed "stubborn" users of the private car, the author believes that if suitable services were provided, many car users who would be willing to switch to public transport.

The second motivation is that an extensive search of the literature has turned up no comprehensive toolkit for the planning and operational management of public transport systems. The work of Vuchic et al (1979 & 1981) and Vuchic (1981) taken together comes closest to fulfilling this. Thus, an apparent gap in the literature exists. Attempting to assemble such a toolkit has led to the development of methods for dealing with the problems of establishing a public transport system from scratch, in a multi-modal, multi-operator environment.

The third motivation is that, in South Africa, recent government policy documents and subsequent legislation require the metropolitan authorities to develop strategic, integrated transport plans. These transport plans are to include public transport and must incorporate such factors as the minibus-taxi re-capitalisation program, contracted public transport services, a goal of an 80:20 public to private transport ratio and several other social objectives. Again, no detailed mechanisms appear to exist for the development of such plans or the subsequent management of such systems.

The fourth and final motivation overlaps with all the others. There are many arguments for the promotion of public transport. There are equally as many counter arguments. There are also a number of targets, specified by the South African government, to be met by the public transport system. It is not always possible to exactly quantify the merits and demerits of each aspect of public transport provision. It does however seem possible to make a reasonable assessment of many of them within the planning area of a local authority. An example of this is the 80:20 ratio: Giving consideration to the damage caused to road infrastructure by buses, the cost of providing public transport services in general, and the resistance of many to the use of public transport, is this a sensible business objective? Is it not conceivable that for some areas, private transport is the best and possibly the only option and that for others a 40:60 ratio would be optimal, and so on? A rational approach to system design with realistic and "profitable" goals and benchmarks is required.

1.3 OBJECTIVE OF RESEARCH PROJECT

As the title of this dissertation implies, its core is a computerised decision support system. The dissertation is not however a "user manual." It is rather, a description of the principles and processes underlying the development of the complete decision support system presented and intended as an aid to system design and management. The decision support system is developed around the principles of strategic logistics management and their application to the planning and operation of transport systems, and more particularly, public transport systems, by metropolitan transport authorities. The managerial skills and knowledge of the transport and public transport industries are still required.

It is the objective of this dissertation to provide a set of techniques for using existing commercial programs for the design and ongoing operational and strategic management of a sustainable and flexible urban public transport system. This is subject to the requirement that the software should be readily and cheaply available and relatively easy to use. The commercial programs, Emme/2, Microsoft Access™, Microsoft Excel™, and LINGO have been used with Microsoft Visual Basic™ as the underlying programming language. Most of the Visual Basic code is fully contained within the Microsoft Access database. Where this is not the case, the full code is provided, on the accompanying compact disc, with a description of its function.

That Emme/2 or LINGO are easy to use is relative. In the case of Emme/2, it is the transport network-planning model most commonly employed in South Africa and there are functional Emme/2 models of most major South African centres. It is primarily for this reason that the Emme/2 package has been used in the development of this public transport planning method. There is no reason that the methods and database cannot be adapted to another network-modelling package. In the case of LINGO, the software is relatively inexpensive and will be readily assimilated by anyone familiar with the mathematical programming techniques commonly used in freight and airline logistics or other fields of operations management and transport planning. Microsoft Access, Excel, and Visual Basic are sufficiently well known, Visual Basic being inherent in several Microsoft Office suite programs, to require no further introduction.

1.4 DISSERTATION LAYOUT

This dissertation is divided into four sections and is accompanied by a compact disc. These sections are:

1.4.1 Introductory section

This section contains all the formal requirements of the dissertation document, the table of contents, this introduction, and a review of the literature pertaining to the work presented herein. This section also includes a chapter on the strategic logistics management concepts as applied to the planning and operation of public transport. This is described primarily in the context of the South African situation where transport authorities are responsible for managing the transport and public transport systems in a private : public partnership which incorporates multiple modes and operators.

1.4.2 Technical processes

The section on technical processes describes in depth the techniques proposed for the determination of the optimal public transport system given the current and anticipated future resources and the social, environmental, economic and political goals current in the region. This section encompasses the function of the computerised decision support system, which has the following components, as shown in Figure 1-1:

1.4.2.1 A transport-planning model. (Emme/2)

This is a modified version of the conventional transport network-planning model commonly developed for urban areas. The modification and associated processes are used to develop public transport paths that take into account:

- Non-transit traffic
- Urban planning considerations
- Multiple operating periods
- All transit modes
- User desire lines
- The practical provision of public transport.

The results are meaningful on their own but may be enhanced by further processing.

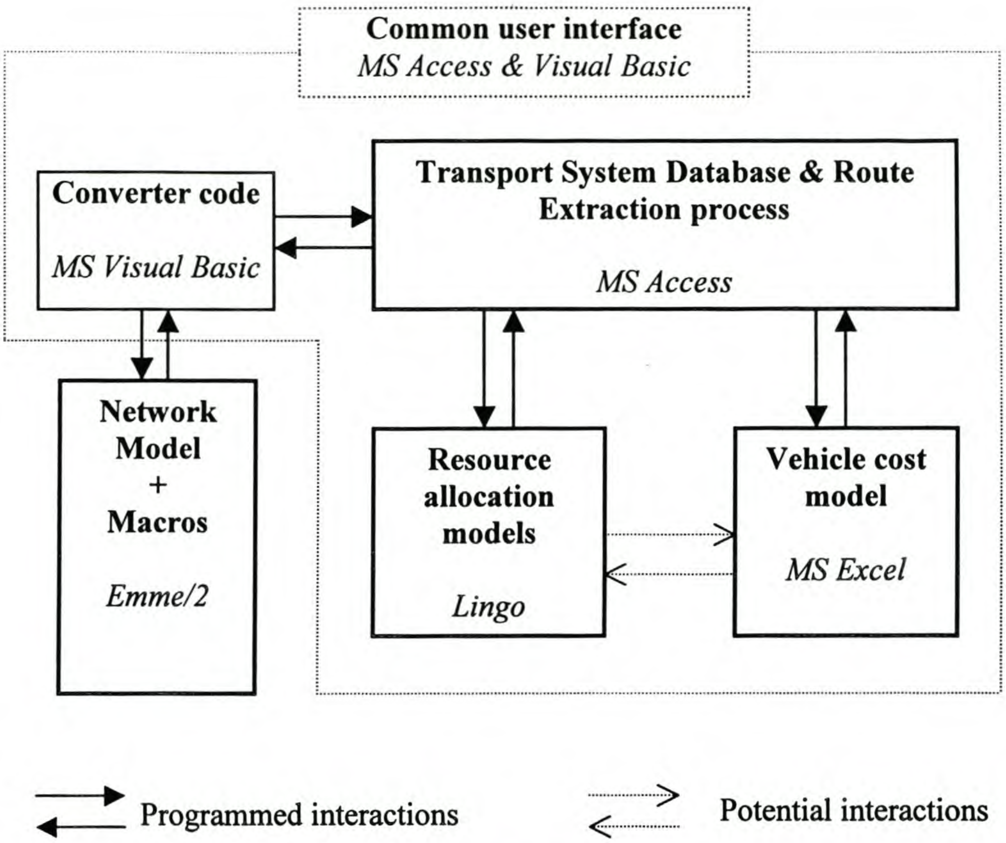

Figure 1-1: A schematic of the decision support system for the planning and operation of a public transport system. (The commercial software used in this model is identified with italic text.)

1.4.2.2 A route extraction program.

This empirical process defines public-transport routes based on the public-transport-network link-demand-volumes. These defined routes support various categories of vehicle and service frequency subject to planner specified criteria. The route specifications provide the physical path, peak section volume, route length, and other information relating to the route itself and to the use of the network with respect to the placement and nature of fixed infrastructure.

1.4.2.3 A resource allocation program.

The primary resource allocation program is a mathematical goal-programming model that is used to allocate existing or potential resources to the defined routes according to prescribed and potentially conflicting objectives. Technical and social issue may be included in the model. An example of a secondary application of this process is given as the basis for developing a full public transport design process for a specific region which is likely to have its own particular considerations and for which it is thus not practical to develop a generic model.

1.4.2.4 A vehicle operating cost model.

This is a spreadsheet-based vehicle cost model based on freight industry standards, taking into account vehicle and staff hours worked as well as operating speed effects on fuel consumption. This model is used to develop input for the resource allocation process but also provides a tool that the public transport authority can use to assist small operators in managing their fleet costs.

1.4.2.5 A transport system database.

This database, (using MS Access,) forms the core of the computerised decision support system (DSS). It is used to store and manipulate information on all aspects of the system including infrastructure and policy data. In the demonstration model presented here, the route extraction program is an inherent part of the database although this need not be the case. The Excel and Lingo models are also stored within the database but the programs are required separately.

1.4.2.6 A small Visual Basic "File Manager" application to enable portability.

This is simply a small executable file that allows the identification of the working data files used to interface between the network model and the database. This cannot be easily incorporated directly into the database but would form an integral part of a DSS structure in which the controlling programme code was not a part of the database.

The section on technical processes closes with a chapter devoted to the auxiliary decision making processes, such as for example, the determination of operating costs and replacement cycles for public transport vehicles.

1.4.3 Case study

This section provides an example of how the public transport network design process can be applied. This is done using a modified version of the Winnipeg model provided with the Emme/2 package.

1.4.4 Closing section

This final section includes conclusions and recommendations as well as supporting material. This supporting material includes a bibliography, a glossary, and several appendices, two of which are auxiliary chapters rather than conventional appendices. These auxiliary chapters discuss the decision support system database in the one case and the data required for the modelling process in the other case. The program code is available within the database on the accompanying compact disc and is not reproduced here.

1.5 THE COMPUTERISED DECISION SUPPORT SYSTEM COMPACT DISC

This dissertation discusses the processes that can be used to design a public transport system from scratch using common software and provides examples of how these processes can be implemented. A detailed description of the decision support system database and the network models brings nothing to the knowledge base and they are thus not described in detail. The database and associated models are however important to the completeness of the dissertation. A compact disc is thus provided with the dissertation document. This CD contains the Emme/2 databanks and macros used in the examples, the database with all the process code, and other supporting material in the form of spreadsheets and mathematical programming models. This document is also on the compact disc.

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2 AN OVERVIEW OF BACKGROUND LITERATURE

Transport planning, in the context of the government authority, is commonly thought of as an engineering function. This is as opposed to transport planning in the commercial sense of goods transport, which is usually a logistics/operations research function. At the government level, national, regional, or local, there is however, a variety of other professionals whose participation is important to the effective planning and operation of the transport system. The skills required include those of engineers, logisticians and economists, urban planners, sociologists and politicians, through management specialists, to psychologists and marketing experts. This diversity of skills is particularly important when planning and operating public transport, which is to be promoted over private transport, as an integral part of the main transport system.

Whilst focusing on the technical aspects of the public transport planning and operating process, this dissertation attempts to unify aspects of the diverse specialities in one coherent public transport planning and operating methodology. This has required drawing on a variety of sources for information and inspiration. With the primary objective of demonstrating the breadth and depth of knowledge required in the transport-system management-team, this chapter briefly presents the important reference sources under the broad headings:

- Operations Research
- Transport planning. (From the authority perspective.)
- Politics
- Urban planning
- Logistics
- Management
- Economics
- Marketing
- Psychology

2.1 OPERATIONS RESEARCH

One of the elements common to many of the disciplines involved in transport is the mathematics of operations research. The principles of operations research are fundamental to the network modelling process and the logistics functions but are employed in nearly all other areas of transportation planning as well. Winston (1994) and Render & Stair (1997) provide examples for almost all the above listed fields.

One common use of operations research techniques, and the one of interest here, is the determination of how best to allocate limited resources. In particular, the concepts of goal programming or multi-attribute decision-making are employed in the allocation of resources to the public transport system. Both the above mentioned references provide a good background to this technique with more detailed information being derived from Ignizio (1976), one of the leading researchers and authors in this field. There are a number of pitfalls in using goal programming as discussed by Romero (1991) and this author's work has provided invaluable guidance in setting up the resource allocation model. Schrage (2000,) has been the primary reference source for the detailed development of the Lingo models, providing valuable insight into the practical application of operations research techniques.

2.2 TRANSPORT PLANNING

In the context of this dissertation, transport planning is viewed primarily from the perspective of the public authority rather than commercial enterprise. In this context, transport-planning literature is mainly devoted to network planning principles. Although there is usually an emphasis on private transport modes, the literature can be split into two main categories between which there is often surprisingly little overlap — **General** (private) and **Public** transport planning.

2.2.1 General transportation planning

General transportation planning literature typically discusses various aspects of traditional four-step transportation modelling and the associated system planning and operation issues. The relevance of general transportation engineering to this dissertation is that standard transport planning methods are used to design public transport routes.

There are many works in this category, three of which have provided the theoretical mainstay for the rest of the work. The work of Papacostas and Prevedouros (1993) has provided the broad basis while the work of Ortúzar and Willumsen (1990) has been used as an in-depth resource in terms of modelling. The INRO Emme/2 Release 9.2 User's Manual (1999) has been used for its significant discussion of the principles employed in the network modelling process and their practical application in Emme/2. Associated with the network modelling process are specialist texts that discuss such issues as volume delay functions, (Spiess 1989 and Branston 1975,) and road vehicle interaction, (Branston 1975.) These are used as the basis for some of the specifics presented in the chapter on network modelling.

2.2.2 Public transport planning

There is a considerable body of literature covering various aspects of public transport planning and operation. However, the most important observation resulting from a review of this literature is that there is nothing offering a comprehensive, structured approach to public transport planning and operation that can be implemented in a holistic fashion. The author seeks to close this gap. Aside from the general transportation planning literature, which invariably includes some discussion of public transport, literature that is more specific can be categorised as follows:

- Overview literature.
- Technically specific literature, usually technical papers and reports.
- Marketing literature.
- Government policy and guideline documents.

Each of the above categories has lent some perspective to the ideas presented in this dissertation.

2.2.2.1 Overview literature.

This group includes a limited range of books presenting an overview of all aspects of public transport. Peter White's "Public Transport: Its planning, management and operation," (1995) is a good example of this type of work. Topics covered range from the social motivations for and the economics of public transport, through vehicle technology to operational planning and management. Whilst important to an understanding of public transport, these works rarely offer detailed discussions on the actual design process. For example, White devotes an entire chapter to discussing network planning. However, no practical route planning techniques are mentioned, rather, the reader is referred to three software developments, VIPS amongst them, for performing route selection. The work does however touch on market and product identification issues, again, in limited fashion.

2.2.2.2 Technically specific

With respect to this dissertation, an important section of the literature is that dealing with very specific aspects of public transport planning. A leading author on public transport systems and operational planning is Vuchic, who has produced a number of works in this direction, several of which are listed in the References section. Two of these works, "Transit operating manual" (1978) and "Timed Transfer System Planning, Design and Operation" (1981) cover many aspects presented in this dissertation in more or less detail. These aspects range from the strategic, through the technical to the marketing and serve as a strong support base for much of this work.

There are also several computer programs for the modelling and operational optimisation of public transport. Amongst these are VIPS for route planning, HASTUS for vehicle and crew scheduling, and Emme/2 for transit assignment on a general transport network. The VIPS package is based on the work of Hasselström whose work shall be discussed later. Each of these packages has extensive supporting literature that includes discussions of the underlying theory. They typically deal with aspects of public transport systems ranging from equipment specific details, through optimal route layouts to user strategies for selecting routes from possible alternatives.

Other works, mostly in the form of technical papers, focus more on the theoretical optimisation of specific aspects of public transport planning. For example, the Emme/2 User's Manual (INRO 1999) discusses public transport modelling with an emphasis on public-transport trip-assignment using the concept of "user strategies" as developed by Spiess. Constantin and Florian (1993,) look at frequency optimisation whilst Fernandez and Marcotte (1988,) examine travel time and operator profit. Byrne (1975 & 1976) studied idealised geometric route configurations in some detail.

In the above cases, except for Byrne, the public transport lines are assumed to exist already and the focus of the studies lies in optimisation of some aspect of the existing line or its use by the passengers. Byrne looks at initial line development with respect to particular geometric patterns. The opportunity to employ such layouts is severely limited in reality and the theory is thus not particularly practical.

2.2.2.3 Marketing

The third type of public transport literature is very operator oriented, focusing on marketing strategies, such as staff training, product branding and so on. This literature, along with specialist marketing literature, is used as the basis for the discussion of the marketing issues surrounding the management of a public transport system.

An example of this form of work is that of Barnes (1989) who covers a broad range of transport marketing issues from freight through bus and rail services. As noted by Vuchic et al in their work of 1978 and again in 1981, whilst recognised as important, for some reason, marketing seems to be a neglected aspect in the literature on the planning of public transport systems in spite of the importance of marketing in specifying and selling the public transport products.

More recently, the Transportation Research Board's, Transit Cooperative Research Program, and particularly Reports 47, 50, 53, and 54 of 1999 focus on the same issue. All these reports reflect a strong move towards a customer or market oriented approach to public transport provision at all stages of planning and operation. Report 54 discusses management, customer service, strategic planning, and so on, and thus has many parallels with this work.

Another interesting specialist publication is that of the Commission of the European Communities, Directorate General for Transport DGVII (1998). This is a set of brochures documenting methods for changing modal choice to promote reduced car use. Whilst the program places emphasis on public transport, it uses a broader transport system approach, looking at cycling and walking and the interaction between these modes to support longer journeys.

Whilst the focus of the dissertation is on technical design issues, these sources provide a background to some of the ideas proposed, incorporating as they do, aspects relating to local authorities, public transport operators, interchange facility managers and environmental campaigners.

2.2.2.4 Government policy and guidelines

Another category of literature of importance in public transport planning is that published by the central, regional, and local governments. Transport infrastructure and public transport services are usually provided, by or through some government agency, based on the policy of higher levels of government.

The key transport policy document in South Africa is the National Department of Transport White Paper on Transport Policy of September 1996. This document specifies the direction to be taken by transport and public transport planning in South Africa. Arising from this base, there have been several other documents, used to identify planning needs and to provide examples of the goals and objectives to be met in the public transport planning process. The most important example in this case is the South African Department of Transport (1998). "Guidelines for preparing the Public Transport Plan: A Component of the Integrated Transport Plan." This latter document provides many useful definitions and specific guidelines used in this dissertation. The main relevance of these government documents has been to identify those aspects of the public transport system that should be given priority in the design process. Most important are those specified in the vision statement of the SA DoT White Paper (1996):

"Provide safe, reliable, effective, efficient, and fully integrated transport operations and infrastructure which will best meet the needs of freight and passenger customers at improving levels of service and cost in a fashion which supports government strategies for economic and social development whilst being environmentally and economically sustainable".

2.2.3 Literature of a similar type to this dissertation

An important part of the literature survey was to determine whether similar work had already been undertaken and what results were achieved. An extensive search for texts fully paralleling the proposals of this dissertation produced very little. However, the work of several authors stood out as being important in the context of the technical aspects of this dissertation. These authors published work on the route design aspect of public transport planning, mostly in a road mode environment and this literature provided a good basis for the proposals presented here. Key authors in this direction have been, in chronological order:

- Lampkin & Saalmans (1967) — Used separate route and frequency determination algorithms due to computational difficulty. The separate route choice, vehicle allocation-frequency approach is used by this author although the use of a focusing process based on the minimum sustainable vehicle frequency introduces a service frequency element into the route design process.
- Rea (1972) — Used a "level of service" approach to route design. This is based on the minimum viable demand and maximum feasible capacity of the modes available on the link. In subsequent iterations, service level is adjusted to reflect trip assignment results. This adjustment of service level amounts to a focusing process similar to that proposed by this author and it seems that Rea was the first to employ this technique.
- Hasselström (1981) — Performed route selection and frequency determination concurrently. He seeks to maximise the total number of passengers using a public transport system by maximising consumer surplus, measured as a generalised-cost. His research resulted in the VIPS (2000) program, which is one of the leading public transport planning packages currently in use.

- Ceder & Wilson (1985) —Use a system that attempts to minimise the difference between the minimum possible travel time and the actual travel time. Their paper also offers a useful survey of other techniques developed up to the date of their study. The focusing process used by this author starts with the minimum possible travel times and then increases some of them until sustainability is achieved.
- Elgar & Kfir (1992) — Used the Emme/2 model to perform a free assignment of public transport trips onto the "loaded" network. This was done by first assigning auto traffic and then using the link travel times as the basis for the public transport assignment. They only looked at road network elements but in many respects, this work is an extension of their proposals. The most important deviations, at the network modelling level, are the concurrent assignment of both private and public transport trips and the inclusion of all modes.
- Dhingra & Shrivastava (1999) — Look at the multi-objective planning approach to route and frequency determination using genetic algorithms, fuzzy logic, and artificial intelligence techniques. The use of multi-objective programming is common to the methods of this author and in fact, they are probably correct in claiming that genetic programming techniques are more practical for this type of problem. They have however focused on a limited aspect of the public transport design problem and their genetic algorithm model will require modification to employ the more open-ended approach adopted by this author.
- Lee & Vuchic (1999) — Solve the public transport network design problem with variable public transport demand within a fixed total demand. They perform concurrent route and frequency determination with a dedicated program. The frequency determination is based on the maximum demand section load only, as is done by this author. Their method is capable of minimising the objective function against a number of possible criteria although they describe the case for travel time minimisation only. Although they have developed a variable demand model incorporating private and public transport modes, it is unclear how they directly incorporate regular traffic impacts on route choice. They appear to use a fixed link travel time rather than allowing for a change in travel time due to redistribution of traffic. They also do not appear to take into account the availability of a diverse fleet.

Lee and Vuchic (1999), who use the example in Rea's (1972) paper to demonstrate their own technique, claim that Rea's technique is not easily implemented in reality. The transport system design method described in this dissertation however, uses very similar principles to those of Rea. Rea uses a "level of service" approach for the various available technology to "focus" trips and thus to design routes. The sustainable frequency approach adopted here is very similar. The main difference in approach lies in the inclusion, by this author, of general transport and policy factors directly into the assignment process. This eliminates the problem, experienced by Rea, of congested road links preventing the achievement of the level of service upon which the design is based.

Another area of difference is that Rea starts by imposing operational constraints whereas the method proposed here prescribes the desired results and seeks the solution set by approaching the problem from the users point of view. Rea evaluates alternatives in terms of what he terms, the impact set, which covers user, operator and government factors arising from selecting a particular route-technology configuration. It is proposed in this dissertation, that the desired impact set be established, and then the public transport system be designed to best meet that desired impact set. In the process of achieving this, the evaluation of alternatives, treated as a separate function by Rea, is inherent in the overall process.

Amongst previous studies, the foremost appears to be that of Hasselström (1981.) His doctoral dissertation, presented to the Department of Business Administration at the University of Gothenburg, Sweden, examines public transportation planning using a mathematical programming approach, much as is done here. The research was sponsored by AB Volvo Transportation Systems, and resulted in the development of the well-known public transport-planning program, VIPS (2000.)

This dissertation does not attempt to evaluate or emulate the work of Hasselström, but rather seeks a broader approach to public transport system design and operation using existing modelling tools as a group to cover a broader range of public transport issues, rather than developing an entire new modelling package as arose out of his work. This broader approach incorporates route design, vehicle allocation, and frequency optimisation as a component of the approach, as done by Hasselström but in less specific detail.

A central point of disagreement with much of the above literature is the general assumption that the level of service of public transport always increases with demand as opposed to the opposite occurring with private transport demand. This may be true in many circumstances but is not universally the case. Large road based transit demand can lead to worsened congestion when private cars and buses are forced to use the same facilities. Where public transport users use park 'n ride or drop 'n ride facilities, unless these are adequate and suitable, there may be a decrease in LOS with increased demand. Finally, congestion of the public transport system itself is perfectly possible and is often reported for large Indian cities and sometimes for European cities such as London. Any public transport design method should thus consider these possibilities.

2.2.4 Supporting literature

Supporting literature is identified as that providing material or ideas used in this dissertation that are outside of the mainstream of public transport planning literature albeit highly relevant. Of particular importance, from the author's perspective at least, is his own Master's thesis (Duff-Riddell 1998) upon which this work follows. This thesis describes the application of strategic logistics management principles to the planning and operation of public transport and can be viewed as an introduction to this dissertation. Supporting literature can be further subdivided into several categories:

- Current thinking in transportation policy
- Management principles from commerce and industry
- Transport psychology related to mode choice
- Decision making
- Planning techniques

2.2.4.1 Current thinking in transportation policy

There appears to have been a significant change in the perspective of transportation planners in the last few years. Some of these changing perceptions can be illustrated by the following:

Goodwin (1997) is of the strong opinion that traditional transport planning is self-fulfilling and that solutions not based on the trends will prove equally or more successful than the standard growth trend models. In tandem with this, is the perception that travel demand forecasts are more often wrong than right and when right, are so for the wrong reasons, (Mackett 1998.) Cox[1] (various) makes a similar claim and extends it to the cost estimates of large projects. In his view, budget estimates for public transport projects are usually low and ridership estimates usually high. The implications are that a different approach is required to transport planning.

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[1] The "Public Purpose" website, which operates as the mouthpiece of Wendell Cox Consultancy, contains a range of resources and papers that are not listed separately. Should the reader be interested, the web address is given in the references.

Cox further argues that many of the conceptions in respect of public transport are not true; that, for example, the typical commuter bus is often less energy efficient than private transport. This is not necessarily the case but is quite conceivable given that a scheduled service must operate irrespective of passenger numbers. Thus, the total energy consumption per passenger kilometre may exceed that used were only private transport used. It is interesting to note that the same source provides many examples of the introduction of the tendered public transport system and the savings that have been almost universally achieved using this approach to service provision.

The Institute of Transportation Engineers, Transportation planning handbook 2nd Ed. (1999 pg. 464,) promotes the idea of strategic management as an approach to public transport planning and operation. Another American institution, the Transportation Research Board, is adopting a similar philosophy. Almost all the recent Transit Cooperative Research Program reports have emphasised the need for market oriented planning and a more flexible approach to service provision in the public transport industry. This is perceived as necessary to deal with constantly changing demands, circumstances, and innovations on the part of other transport-market role players. In particular, TCRP Report 53 (1999): "New paradigms for local public transportation organizations," should be viewed as essential supporting reading for this dissertation. For the sake of completeness, a few extracts from the executive summary are presented here. These extracts serve to support the motivation for, if not the content of this dissertation:

> *"There is a broadening recognition at the local level that a wider array of travel options is needed to sustain economic growth in major metropolitan areas and to guarantee access to opportunity and basic human services in both small and large communities."*
>
> *"Current and emerging circumstances require fundamental reinvention of how public transportation services are organized, designed and delivered."*

A list of reasons for change, all of which are applicable to the South African situation is given and are quoted verbatim:

- *"The shift in federal funding away from support of transit operations and the competition for funds at all levels of government;*
- *The marginal performance, high cost and fragmented responsibility that characterize public transportation today;*
- *The societal trends that increasingly reduce the attractiveness and relevance of traditional public transportation services;*

- *The inability to reconcile competing or contradictory transportation goals and objectives in today's public policy arena, e.g., support for economic growth vs. environmental protection vs. cost control;*
- *The fact that traditional measures of performance in transportation, e.g., vehicle flows, are not aligned well with broader community goals and expectations, e.g., quality of life, liveability, accessibility, etc.; and*
- *The fact that fundamental changes and paradigm shifts are occurring in businesses and industries, providing important models on which fundamental change in public transportation organizations can be modelled."*

2.3 POLITICS

Transport is an essential element of the economic, social, and strategic well being of a country. Consequently, it is one of the independent portfolios of most governments and is driven by political as well as practical motivations. Politicians are the social engineers of society, trying to mould society to their view of how it should look. Simultaneously, politicians rely on votes from the general populace to sustain their position and thus tend to favour projects that will be acceptable to their supporters, even if not ideal in the long-term. The result is that policy documents are often not strongly backed by action and funding. The planners and operators must keep this in mind as it means that their plans must find the balance between government's policy and its chequebook.

The presiding government perspective of how development should take place is usually set out in a variety of policy documents. In South Africa, the key documents at present are the National Department of Transport White Paper of September 1996 and the Moving South Africa document, "Towards a Transport Strategy for South Africa for the year 2020," of September 1997. These policy documents cover transport as a whole. Their importance lies in establishing how public transport fits into the overall government policy for transportation.

The policies presented in these documents devolve down through provincial government to city, and possibly even lower levels of government and form the basis of the local transport planning process. Failure to comply with the policy requirements will probably lead to rejection of the planning proposals and thus they must form the basis of any planning process.

In South Africa, the government policy places a strong emphasis on public transport and the concept of customer service for the entire transport sector, the terminology of strategic logistics management often being used in the policy documents. There has also been a move, as has been occurring elsewhere in the world, in the direction of more socially oriented planning objectives and performance measures. An example of this thinking is to be found in the paper by Bougromenko and Myasoedova (2000) who refer to the concept of "humanitarian indices reflecting standard of living," as opposed to the technical indices commonly used. This is done with reference to strategic planning for sustainable development.

2.4 URBAN PLANNING

Urban and transport planning are inseparable at any meaningful level. There is debate about which is the driving force, but this is not relevant here. What is important is that for a variety of reasons, certain forms of urban development exist or are promoted by the planners and politicians and must be supported by transport plans. The public-transport network-planning process proposed here incorporates an element that allows for the promotion of urban planning objectives. It is thus important for the public-transport planner to be aware of these objectives and to interact with the urban planners in the transport planning process.

In Cape Town, South Africa, the Cape Metropolitan Council "Metropolitan Spatial Development Framework: A guide for spatial development in the Cape Metropolitan Functional Region. Technical Report April 1996" represents an example of a comprehensive urban plan that must be supported by a suitable transport plan. This particular urban model seeks the creation of activity corridors linking activity nodes. These are intended to reduce commuting distances by encouraging economic development at the nodes and along the corridors. At the same time, densification is being encouraged along the corridors and around the nodes with a view to limiting urban sprawl and facilitating the provision of services.

The transport plan can be used to support the urban development plan through designing services and facilities assuming the urban development plan to be on track. (Whether or not the desired development results will be achieved is of course another question.) Focusing public transport demand onto the proposed corridors wherever feasible supports corridor development. This is done on the assumption that a strong transport service will encourage development, and thus densification along the corridor. This does of course require that the availability of such transport be strongly promoted to potential developers. Development at the nodes can similarly be encouraged by seeking to place interchange facilities at or near these nodes. Ideally, small but existing nodes are selected as the core of more ambitious growth. How this is done in the modelling process whilst maintaining an emphasis on customer service will be discussed in detail in a later chapter.

2.5 LOGISTICS

Ensuring that the right things are in the right place at the right time and in the correct quantities is the function of logistics. The same criteria apply in all fields of activity, with examples ranging from military operations through industrial plants to commercial operations. (An example is given in Lambert and Stock (1993 Pg.4.) of stock brokers using logistics to improve their business.) The main source of reference and in fact the basis of this dissertation has been the work of Lambert and Stock, "Strategic Logistics Management" (1993.) An entire chapter being devoted to this subject no more need be included here. Implementing the logistic plan is one of the functions of management, which is thus an important area with respect to the planning and operation of public transport.

2.6 MANAGEMENT

Management is a function that brings together the skills of many specialists, evaluates their advice, and then makes informed decisions in attempting to promote the business being managed. There are thus two aspects to management. The first of these is an understanding of the business and each of the specialities required to make it function. The second is an ability to achieve consensual decisions so that all role players willingly work towards common goals. These two requirements are reviewed under separate heading.

2.6.1 Operational management

A business rarely survives on only a good product or even a monopoly for a vital commodity. Ultimately, the success of the business relies on the careful planning of the entire production, distribution, and marketing process. In spite of the fact that the products and associated processes may differ widely, the fundamental management principles remain the same. Thus, public transport, which is not a popular product, needs good management if it is to be viably produced and marketed. Assuming an understanding of the specifics of the public transport environment, this dissertation is based on the principles of strategic logistics management as propounded by Lambert and Stock (1993.)

In support of the proposals of Lambert and Stock, the work of Lockyer (1983) is used to broaden some of the perspectives. The former authors focus on the management of the flow of materials and goods from source to customer while the latter author is concerned primarily with production management in factories. It is however, surprisingly easy to transfer many of the ideas from both works straight to the public transport environment to give a structure to the planning and operating process.

2.6.2 Consensual decision making

Public participation in local authority decision-making has become an important part of modern life, often being required by legislation. Transport decisions, which impact on communities in such a broad way, are particularly subject to such participation with strong reactions often being received from focus groups, ranging from business interests to environmentalists. There have been a number of papers written on the subject of such public participation. Two, which focus on transport in particular, are those of Schwartz and Eichhorn (1997) and Richardson and Kostyniuk (1998.) Both papers focus on multi-attribute utility analysis to evaluate alternatives given the diverse views of role players in the decision making process. These techniques are necessary for the implementation of the resource allocation process where the relative importance of various criteria must be established. Although implicit in all planning decisions even when made by one person, emphasis on the multi-role player aspect is important if the public transport product is to be marketable.

2.7 ECONOMICS

Economic viability of the transport system and the public transport system are vital to their long-term sustainability. Management must be able to perform economic evaluations in order to assess the strategic viability of its proposals. Such economic evaluation spreads across the full gamut of public transport, including as it does infrastructural, social and operator level economics. Of particular interest and relevance to this work have been the books by Lowe (1989,) and Cooke (1974 & 1978.) These authors examine fleet operation and pricing in an inflationary economy. These, along with the South African Road Freight Association (1995) costing schedules have been used as the basis of the costing for vehicle allocation and vehicle replacement cycles.

The Cape Metropolitan Council "Guidelines for conducting the economic evaluation of urban transport projects" (1995) has provided a perspective on the local government approach to economic evaluation of infrastructure.

2.8 MARKETING

An important aspect of any form of business is marketing. The marketing function is the interface between the business and the customer, both in determining the product attributes most likely to satisfy customer demands and in informing the customer of available products and persuading them to buy those products. Since it is such an important component of the management function, its basic principles and role in the industry must be understood. Many marketing issues are covered in the management and transport psychology literature already mentioned. Marketing, in the advertising sense, is an art in itself and for this, the work of Seiden (1976) has been used as an introduction to the field. Barnes (1989,) mentioned earlier, is also of relevance as he provides a meeting of management and pure marketing in public transport.

2.9 PSYCHOLOGY

Many of the issues in transportation are based on the choices made by users of the transport system. The reasons for the choices made are rarely based exclusively in fact and rational thinking. A variety of perceptions, based on experience, peer pressure and advertising influence peoples choices. Understanding of the choice making process and the factors which influence perception and acceptance are important to all levels of transport planning and operating as well as to urban planning and political manoeuvring. Steg (1995) and Stradling et al (1998) provide information on the psychological issues important in transport planning. These are important not only in the marketing of public transport, but also in its design where operational and equipment factors may play a role in the behaviour of potential customers.

2.10 SUMMARY

As can be seen, there is a broad knowledge base required to comprehensively plan and operate a public transport system. Neither all the topics are, nor all the mentioned literature is specifically covered in the remainder of this dissertation. This chapter has served rather to provide a background to the following chapters, highlighting the influences that have lead to the approach adopted by the writer. A more comprehensive list of reading can be found in the Bibliography. The following chapters will attempt to bring the variety of topics discussed in this chapter into better perspective within the overall public transport planning and operating process.

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3 STRATEGIC LOGISTICS MANAGEMENT

In any business, we must clarify what it is that we want to achieve, why and how. The reason for most business is to generate a profit by supplying a good in demand. In urban transport, this is not exactly the case. Rather, urban transport is provided to ensure the sustained well-being of the community by meeting a need, profit per se is not a motive. This well-being is measured in terms of social, economic, and strategic values. One of the components of the urban transport system is public transport. In assessing the reasons for operating public transport, we may ask ourselves the following questions:

- Is basic mobility provided for all the citizens of the region? What is it worth to do so? What are the consequences of not doing so?
- Are the needs of incidental travellers, tourists in particular, provided for? What is the value of their custom to the region as a whole and what is lost through not providing adequate public transport services for them?
- Is the long-term cost of congestion outweighed by the current cost of providing an under-utilised but attractive public transport system which forms the basis of a program to encourage public transport over private transport?
- In the event of a serious fuel shortage, does the metropolitan area have the infrastructure to keep other aspects of the economy functional by being able to provide public transport services? What is the risk of this happening? What is the value of precautionary measures?
- In the event of an emergency – a natural disaster of some sort for example – does the metropolitan area have the capacity to move those who need moving and cannot do so under their own steam? (This is an important issue in a country like South Africa with many poor people with no transport of their own.) Can the transport system cope if everyone uses private transport modes?

The answers to these questions show that public transport is necessary to ensure fulfilment of the requirements of an urban transport system as well as to mitigate some of the problems arising from the transport system. More specifically, we want to operate a public transport system for the following reasons, amongst others:

We want to maintain a practical operating speed on our roads.

1. We want this because, especially for those already using road based public transport, travel times are often excessive, and this reduces work place productivity and quality of life in general.
2. We need to ensure that emergency and public transport services can operate efficiently.

We want to reduce the number of cars on the road during peak hours.

1. In order to achieve reasonable operating speeds, we must either reduce the number of vehicles or increase the number of lanes. The latter is expensive in all respects.
2. The amount of space utilised for parking in the commercial and industrial centres is high.
3. The energy consumption and pollutant levels need to be limited for environmental sustainability.

We want to provide an efficient public transport service.

1. To cater for all those in the community who cannot currently afford private transport and whose use of private transport would result in a total gridlock of many roads.
2. To provide for visitors and others for whom private transport is no option at all.
3. To enable private transport users to change to a more efficient mode and thus to free up the road space necessary for the maintenance of a practical operating speed for emergency services and those who have no choice but private transport.

We want to provide the least environmentally damaging transport system.

1. Because we only have one environment. If it is ruined, we cannot replace it.

We want to provide a sustainable transport product range.

1. The resources available for providing transport are limited but the demand for transport is continuously increasing. We need to ensure that the resources are used to their maximum potential so that efficient transport is available for all users and potential users, now and in the future.

We want to maintain a strategically important component of the transport system.

1. To provide transport in emergencies.
2. To provide transport for those having no alternatives.

3. To support other social and economic goals of the country. (For example, school buses are important to the education process that in turn is important to the future growth of a country's economy.)

Thus, we operate public transport because it is a necessary component of the overall transport system and in so doing, we seek to minimise certain costs and achieve certain strategic objectives of the overall transport system. We operate the transport system to ensure the mobility of goods and people and the accessibility of services and social activities and hence, "strategic logistics management."

3.1 SOME DEFINITIONS

The term "strategic logistics management" is one that bears some analysis before venturing into further detail:

The Webster dictionary gives the following definitions:

Strategic — Of great importance within an integrated whole or to a planned effect.

Logistics — The handling of the details of an operation.
— The process of planning for and providing goods and services.

Management — Judicious use of means to accomplish an end.

Other definitions of management are:
— Manner of directing or of using anything.
— Administration of business concerns or public undertakings.

We may thus translate the term "strategic logistics management" as:

> The judicious use of means to plan for and provide goods and services of great importance within an integrated whole and to a planned effect.

This definition, whilst not the formal one that shall be examined shortly, is equally valid at all levels of business and government. It can be applied by the board of a large company and by the canteen staff at an office of that company. Similarly, in the transport industry, what is good for the whole system should be good for each of the components, given that the relevant objectives of the higher level must apply at the lower level. In public transport, this results in a hierarchy of objectives ranging from those of national government through the various levels of regional and local government, who represent the community as a whole, to the operators of the vehicles.

One more definition is worthy of attention. As has been seen, the public transport system is a part of the general urban transport system, a part of the integrated whole. This has lead to the use of the term, “integrated transport.” What does this mean, especially in the context of public transport? Cole & Lloyd (1997) offer the following definition:

> *A well integrated transport system is one which in the judgement of the actors in the system has the best possible relationships between transport and land use, between public and private transport and within public transport to deliver the quickest and environmentally least damaging service.*

3.2 THE PUBLIC TRANSPORT BUSINESS

Given a reason for providing public transport and its place in the urban transport structure, the next step is to recognise that public transport is a product. It must be produced and marketed, in turn requiring a structured organisation — the public transport business, which shall be abbreviated as the PTB in the rest of this dissertation. The PTB is an organisation comprising many role players or “departments.” There are the operators, the local and regional authorities, infrastructure managers, vehicle suppliers, and so on. These all serve the customer, either directly or indirectly. Some are in it for the profit, others, as mentioned have more socially oriented objectives. All will benefit from an improvement in the performance of the PTB.

The PTB must itself have a set of guiding principles. Some as mentioned would come from higher levels of the transport business but these and internal ones must be clearly established if the business is to operate efficiently.

In order to measure its performance; a business must first define its goals and objectives. These are typically embodied in vision and mission statements that clearly define the direction of the business and its core focus and are accessible to all staff and other role players.

Torok (1999,) defines vision and mission as follows:

> **Vision:**
>
> "Vision is a big picture statement. It must be powerful, summarised in one memorable or motivating sentence or phrase. It should be general in scope, not restricting."
>
> Star Trek: *Space—the final frontier*

The South African government (1996) has provided a vision statement for the transport authorities that has more or less universal appeal:

> *"Provide safe, reliable, effective, efficient, and fully integrated transport operations and infrastructure which will best meet the needs of freight and passenger customers at improving levels of service and cost in a fashion which supports government strategies for economic and social development whilst being environmentally and economically sustainable".*

Mission:

"Mission is the answer to 'What am I going to do about my vision?' This is more general than specific. The mission must inspire you and your customers. It points the direction you are heading. It is not the map just a compass heading."

Star Trek: *To seek out new life, to boldly go where no one has gone before.*

The South African Department of Transport has proposed the following, which could be used as its mission statement for public transport: (Undated briefing paper: "Major steps under way to improve public transport in South Africa")

- *To promote the use of public transport over private transport*
- *To ensure that public transport services address user needs, including those of commuters, scholars, tourists and the disabled*
- *To promote and implement a system of regulated competition for tendered public transport routes*
- *To assist and economically empower disadvantaged operators to participate meaningfully in the public land passenger transport system*
- *To ensure that operations become more economically viable, requiring the minimum financial support, and*
- *To promote safe and secure, reliable and sustainable public transport.*

Having the vision and mission statement are not however a substitute for effective management and it is the philosophy of "strategic logistics management" (SLM) that is used as the basis of this dissertation. Following on from the broad definition of SLM given above, the Council of Logistics Management gives the following more formal definition. (Lambert & Stock, 1993, Pg. 4.)

> *The process of planning, implementing and controlling the efficient, cost-effective flow and storage of raw materials, in-process inventory, finished goods, and related information from point-of-origin to point-of-consumption for the purpose of conforming to customer requirements.*

In the environment of public transport, as an integral part of the larger transport system of a region, the following modification of the formal definition is proposed (Duff-Riddell 1998):

> **The process of planning, implementing and controlling the efficient, cost-effective flow of route-seats from point of origin to point of destination for the purpose of conforming to customer requirements.**

3.3 THE SLM PROCESS.

The SLM process, depicted schematically in Figure 3-1, starts with the development of a broad-brush strategic plan, a long-term vision of the future state of the business. This is then refined until benchmark and target values for all the important criteria are determined. Once these values are achieved, a plan is developed for attaining the specified target.

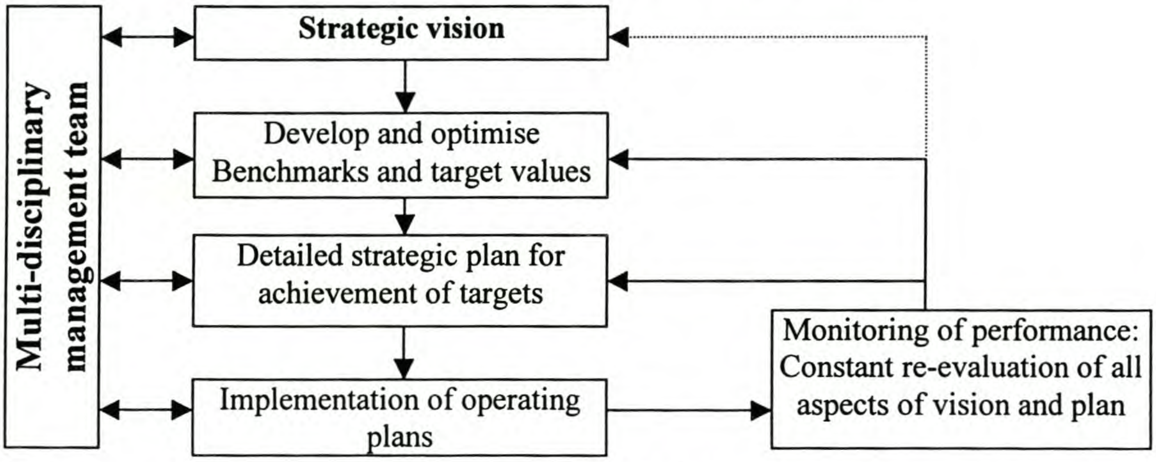

Figure 3-1: The Strategic Logistics Management Process.

The strategic plan can only be successful in the long-term if the implementation is constantly monitored and re-evaluated in terms of changing circumstances. Although the essential strategic vision should remain, even this must be modified from time to time in order to remain relevant given changing conditions.

3.4 FUNDAMENTAL SLM PRINCIPLES

The following extracts from Lockyer (1983, pg. 15,) help to outline the problem that SLM seeks to tackle. The first describes the core problem:

> Too often the production unit is regarded as a self-contained, self-sufficient body, and its dependence upon integration with the rest of the system is recognised only when other parts of the enterprise change.

He goes on to give several examples of the potential problems of this isolationist outlook, including the following:

> Similarly, a board decision to change from a selling policy, where orders are accepted, to a marketing policy, where orders are sought, will inevitably demand major changes in the whole system of production, and again, these can be foreseen if the manager looks outwards as well as inwards.

And finally:

> It is only when the production unit is understood to be part of a whole — a subsystem within a system — that its management can be truly successful.

SLM attempts to deal with these problems by always considering the impact of decisions in one area of the business on other areas of the business. The main tenets of the SLM approach are:

- **The business must achieve a prescribed level of customer service in order to remain competitive or increase its market share.**

- **In adapting to achieve this desired level of service, all components of a business must be seen in their context with all other components of the business. That is, there must be unanimity of purpose within the organisation.**

- **Any change made must produce a net benefit to the whole business, although it may produce a localised disbenefit in some specific aspect of the business.**

The last point is supported by Moran as quoted in Lockyer (1983, pg. 15.)

> The optimisation of the total enterprise frequently requires the sub-optimisation of its component divisions, but it is always difficult to get divisions to graciously accept such restraints on their objectives.

This is even more difficult when the "divisions" are independent operators as is often the case in public transport. An occurrence of this disbenefit can be foreseen with a fuel price increase. Given that road based public transport modes are usually diesel or petrol driven, when the price of fuel goes up, so do operating costs. Electric modes, such as trains may be unaffected by the fuel price increase and will thus have a market advantage which they could exploit in a number of ways. Within the SLM approach, the total cost increase arising from the fuel price increase may be evenly distributed across all modes, lessening the impact, positive or negative, on any of them and improving their viability against the private car. This negates the individual advantage of the electric modes but gives advantage to the entire public transport system

Manheim (1979, pg.178) presents a simple but useful representation of these conflicts. A version of his representation, modified to reflect the public transport environment, is depicted in Figure 3-2.

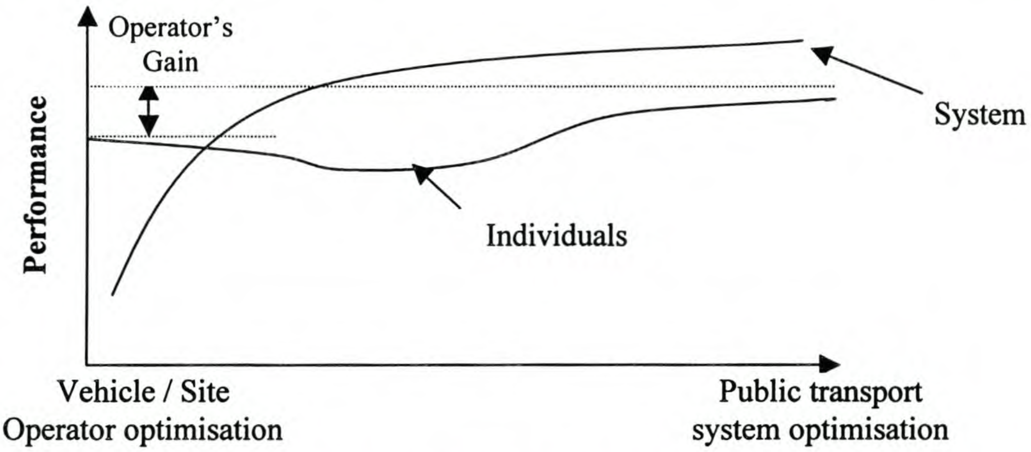

Figure 3-2: Individual versus organisational optimisation.

Given these management principles, in order to achieve our vision and mission, we need a model by means of which we can determine how best to achieve our objectives and goals. The following model is adapted from the SLM model proposed by Lambert and Stock (1993.)

3.5 THE SLM MODEL

The strategic logistics management model comprises two main sections:

- **Given the Marketing objective:**

e.g. Achieve a target share of the (commuter) travel market.

Allocate resources to the marketing mix to maximise the long-run sustainability of the transport system.

In essence, this means providing the right product at the right place, time and price.

- **Achieve the Logistics objective:**

Minimise total costs given the Customer Service Objective where:

Total costs = Fleet operating costs + Fleet size & composition costs + Vehicle selection & routing costs + Access node & interchange costs + Order processing & information costs

Since the products and the customer service objectives, which drive the logistics objective, are established by the marketing function, this is the next topic of discussion.

3.6 MARKETING

It the PTB wishes to achieve the target market share, given the vigorous marketing campaign of the chief competition, the motorcar industry, it must adopt a dynamic marketing policy, where orders are sought rather than a selling policy, where orders are accepted. Marketing is vital to the survival of any business. It provides the marketing information necessary to produce, place and price the goods being sold as well as informing the purchasing public of the availability of goods and their advantages over the competing goods.

The first thing is to identify the product more carefully: Barnes (1989) suggests that the passenger transport product is "accessibility." "Sustainable accessibility and mobility," may be a better definition these days, incorporating as it does current concerns. Sustainability, being with respect to economic, social, and environmental issues is high on the agenda of political and environmental groups alike. Mobility, ease of movement or speed, is a major consideration in modern travel. (This is not to be confused with travel time, as many people are willing to travel long distances to satisfy other objectives, but wish to travel those long distances by as direct and quick a route as possible.) The public transport product is a particular category of the transport product that the PTB has decided to produce and market. Within this category, many specific products can be produced, packaged, and marketed.

It is the function of marketing to determine which of these specific products to produce and how best to package the product and subsequently to persuade people to buy the product. Because they operate within the business and cannot waste resources, the marketing department must know where to place their efforts to best advantage.

3.6.1 Defining the products

A key factor in defining the product is recognising the limitations of advertising once the product is on the market (Seiden, 1976.) Advertising:

1. Cannot sell a product to someone not in the market for it.
2. Cannot sell a product to someone who cannot afford it.
3. Cannot make a satisfied customer.
4. Cannot save a bad product.

In defining the products to be produced, the PTB must keep these points at the fore.

3.6.2 Potential customers — Logical prospects

There are two main categories of customer or potential customer for public transport. Those who have no choice but public transport - captive riders, and those who are in a position to choose to use public transport – choice riders. Those who could reasonably choose to do so but do not are termed logical prospects. That is, they are people who could possibly be persuaded to use public transport if the right product and motivation were provided.

Given the cost of doing otherwise, the planning process can be expected to start with improving the service for current users. This should be done keeping two factors in mind:

- The cost of the service must not place it out of the range of the captive riders.
- Improvements should tend to make the service more acceptable to the current best logical prospects.

The provision of a public transport system requires a relatively predictable demand for transport, both temporally and route-wise. Consequently, the first logical prospects would be those whose travel patterns are relatively rigid, commuters. Those who work regular hours and travel the same route on a daily basis are the most likely to switch. The mode to which they switch will of course depend on availability of services. Similarly, those in a community where many already use public transport are more likely to switch to public transport than those living in areas with little or no current use of public transport.

Over time, if the marketing campaign is successful, then the actual people being targeted will change, as earlier prospects will already have been persuaded. What should have happened though, is that the service being offered should have improved to include new groups amongst the logical prospects, perhaps by introducing new routes which make the use of public transport relatively convenient.

A program to encourage new users should start with areas where good existing services are already provided. Thus, residents along railway lines may be a good start. Any commuter who lives close to a public transport access point, which provides access to their place of work, is a candidate. The marketing department needs to examine the market closely using whatever techniques are available. A typical approach is the use of stated and revealed preference studies. These techniques are well documented and the reader is thus referred to, for example, the work of Pearmain et al. (1991.)

3.6.3 Satisfied Customers and bad products

No matter how good an advertising or marketing campaign is, if the product being offered for sale is not up to scratch, it will not sell, at least not for long. Thus, the product being marketed must be designed to appeal to the customers at whom the service is aimed. A very cheap or even free service offering little more than safe transport must be marketed only to the very poor. A luxury coach with onboard catering must be advertised to high-income potential users and the product must live up to all promises.

Irrespective of the level of service being offered, the product on sale must be of sufficiently high quality that trial users, encouraged by the advertising campaign, will be persuaded to use the service again. A bad product, once tried and found to be bad, will discourage the potential users from trying, even an improved product, again in the near future.

3.6.4 Customer service objective

Having established the form of the products that can reasonably be expected to succeed given a proper marketing campaign, the marketing department, in conjunction with the production department, must develop a set of customer service objectives. The customer service objective prescribes how closely we are going to attempt to satisfy customer expectations and more particularly, the level of quality we need to provide in order to capture and hold market share. For example, what service frequencies and levels of timetable accuracy are we going to aim for? The more rigorous the customer service objectives, the more expensive the product, and price is itself, one of our objectives, and so a trade-off is needed. This is no mean feat in the case of public transport, which is not driven by the same forces as some other products. It should be kept in mind that we seek to encourage, rather than force people to use public transport. This involves providing a suitable quality of service and changing traveller perceptions through a strong marketing campaign. People must want to buy the product and must then perceive it as being worthwhile to continue to do so.

Since the public transport system is operated on behalf of the community, the impact of the transport system on that community needs to be noted. Thus a primary issue in the setting of objectives for public transport provision, is that the entire community should be represented, not just the private car user or the public transport user or operator. In applying the strategic logistics management model to public transport therefore, it is necessary to answer several questions:

1. What are the political, social, and strategic objectives of the authority responsible for the overseeing of the public transport system and how do they propose to support those objectives?
2. What factors influence mode choice locally and how can these factors be modified to maximise public transport usage without the imposition of unduly restrictive measures on car use and thus choice?
3. What resources are available?

The answers to the first two of these questions give rise to the customer service objective that describes the system in terms of performance benchmarks. A few examples are:

- Average walking distance to a public transport access point.
- Quality of vehicles. Measured in terms of a set of criteria such as age, seating space per person, on-board amenities, etc.
- Maximum fares.
- Frequency of service.
- Effective travel speed of all travellers, public and private.
- Maximum cost of the entire transport system to the community.
- Pollution generation rates per passenger-km by all modes, public and private.

Somehow, these measures must be established and quantified in some way. The exact quantification is not always that important, but a relative quantification is. The establishment of these measures and their relative importance can be determined using co-operative decision making procedures as outlined by Richardson and Kostyniuk (1998), and Schwartz and Eichhorn (1997). These authors essentially describe a structured approach to achieving consensus within small groups of "elected" representatives of different viewpoints. The results of such processes are used as the basic design criteria for the public transport system.

3.6.5 Selling the products

Having determined the target market and specified the customer service objectives, which are to drive production, the marketing department must set about selling the product. The marketing campaign must be constructed around three main points:

1. The product on sale.
2. The logical prospects being targeted in the marketing campaign.
3. The unique advantage(s) of the product(s.)

These points must be specified shortly and concisely if a successful advertisement is to be created.

The product will be public transport as a whole or some specific service within the public transport sector. Emphasis on specific products is more likely to attract users who are thus informed of a service that they can use, rather than a generic product that they then have to find out more about by themselves.

When the product is public transport in general, then the target market is all logical prospects for public transport. On the other hand, when only a specific product is being marketed, the logical prospects are those who will actually be able to and are likely to use the service. Do not advertise the luxury coach in a low-income area. Do not advertise any specific service out of its area of activity unless it serves a special market, such as tourism.

In order to persuade potential users to change from car to public transport modes, they have to be persuaded that there is a good reason for them to do so. This reason is the "unique advantage" of the public transport product. An example may be the ability to read a book on the way to work. Other examples may be onboard catering, faster travel times, lower overall costs, safer travelling etc. The campaign may include any or all of these but preferably in separate advertisements to avoid information overload blocking the purpose of the advertisement.

3.6.6 The form of the marketing campaign

It is important to remember that public transport is part of the urban transport system and that one of the reasons for operating public transport is to reduce private car usage. The advertising campaign, marketing the PTB is thus also part of a traffic demand management campaign and should thus be constructed and financed to reflect this.

The form of the marketing campaign is, strictly speaking, a subject for marketing specialists, it is however worth looking briefly at some considerations. Firstly, one of the reasons for commencing such a campaign is because people have chosen the private car over public transport. Most however, are unaware of the true cost and impact of their choice. Some of course are aware of both and still consider the private car to be first choice.

Thus, it would seem sensible to adopt a two-pronged approach to a marketing campaign advocating the use of public transport.

1. Tell the logical prospect exactly what the relative costs of the alternatives are. For example, "The operating cost of a private car is approximately R0-60 per km. The parking will cost R5-00 per day so a journey to work and back of 15km each way will cost about R23-00, excluding all ownership costs. The same bus trip will cost R12-00."
2. Tell the logical prospect why personal gratification may be disadvantageous, even to him- or herself. For example, "Your use of a car, combined with that of your friends and neighbours adds X tons of pollutant to the atmosphere through congestion exhaust, fuel production and other factors. Pollution kills!" In this latter case, identifying something, which impacts negatively on the average prospective customer and showing how another's use of that same thing affects them badly may be of some use. For example, how does the prospective customer feel about the freeway required through his front garden to accommodate increasing demand for road space?

3.7 LOGISTICS — MINIMISING THE TOTAL COST OF PRODUCING THE PRODUCT

In achieving the marketing objective, we wish to minimise the total cost of providing the service without forgoing the customer service objective. In the application of the strategic logistics management principles to public transport, the concept of total cost should be extended to include community costs and benefits. Examples of this are:

- The tax rates ensuring adequate levels of transport infrastructure funding.
- The safety of suburban streets for pedestrians.
- The air quality and noise levels within the local environment.

At the same time, the operational costs of public transport need to be known so that the efficiency of services can be monitored. Ultimately, the authority should seek to minimise the total cost of transport provision to the community whilst meeting its commitment to social and economic sustainability.

Whilst the strategic logistics management model must necessarily include all aspects of the management process, the decision support system focuses upon the logistics function. The marketing function, the importance of which cannot be overemphasised, has been briefly discussed and should be dealt with by specialists in that field. The remainder of this dissertation is thus devoted to discussing mechanisms for the design and operation of a public transport system from the logistics perspective but with SLM as the basis for the enterprise.

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4 THE NETWORK MODEL

4.1 INTRODUCTION

In the strategic logistics management environment, public transport must be planned and operated as a component of the broader transport system. This chapter describes how this can be achieved whilst taking into account customer service objectives, production factors, and strategic objectives. The process starts by determining the network of minimised generalised-cost for customers in a "perfect" public transport system and moves in the direction of community optimality in seeking the point of operational feasibility and sustainability.

The public transport modelling process described here fulfils the strategic logistics management requirement of system integration in several ways:

- At the urban transport system level, it concurrently models both the private and the public transport on the same network.
- At the public transport system level, all public transport modes are viewed as a seamless entity.
- The design process takes into account a broad spectrum of interests in addition to those of the customers.

It is reasonable to assume, as pointed out by Smeed and Wardrop in 1964 that if everyone used only public transport, travel times during peak periods would be significantly reduced for everyone for two reasons. (Goodwin (1997) from the paper 'An Exploratory Comparison of the Relative Advantage of Cars and Buses in Urban Areas' by R. Smeed and J.G. Wardrop.)

- There would be no network congestion of consequence.
- The demand would be sufficient to justify very high service frequency and broad area coverage.

In most people's eyes however, the ideal mode of transport from an individual point of view is the motorcar although many cannot afford one and others choose not to use one for various reasons including a sense of social responsibility. In spite of the perception of the private car as the ideal mode, it can nevertheless be assumed that if the service provided by public transport were sufficiently good relative to private car use, many more people would use it. There will always be those by whom the private car is perceived as the only acceptable alternative, but this may yet prove to be an unsustainable alternative, especially in old European cities with limited space. In addition to the above, it is likely that if everyone used public transport, the cost of transport infrastructure would be significantly reduced.

The perceived superiority of the private car is at least partly due to the fact that a car user decides to make a trip, climbs into the car and takes the route perceived to offer the best utility. What would happen if the public transport user could do the same? This is the starting point of the modelling approach presented here. If the private car is seen by customers as the ideal, then it makes some sense to start the design of a public transport system by trying to emulate private car travel with the public transport system.

The network model is thus set up in such a way as to allow public transport users to act as if they had a motorcar. Initially, their route choice, is influenced by travel time deriving from the interaction of their trip with the trips of other network users based on the existing network, its physical limitations and policy related factors. This is referred to as the "free" assignment of public transport trips to the network and results in users choosing the path with minimum generalised-cost. This usually implies minimum travel time given the actual travel times on the network links. The focusing process employed later moves away from this minimum until an achievable actual travel time is reached based on viable service provision. This is similar to the approach adopted by Ceder and Wilson (1985) of minimising the difference between the minimum travel time and the actual travel time.

For all that the process starts by modelling public transport customers as behaving as if they had private transport, other factors must also play a role in the design process. In public transport planning, there are three groups to be considered:

- The customers
- The service providers
- The community

The customer seeks to minimise his or her generalised-cost of travel between particular origin-destination pairs at a particular time, as described above. The service provider seeks to maximise the profit derived from, or alternatively minimise the cost of, providing the service.

The last group includes all members of the local and often the regional, national, and even global community. For the community, the objectives are generally somewhat different from those of the customers and operators and focus on sustainability of the community, be it environmental, social, or financial. This sustainability issue impacts on the extent to which private car travel is to be discouraged, public transport subsidised and certain urban planning proposals implemented.

Traditional transportation modelling is based on predicting how trip makers are likely to use the transport network given various system characteristics. It has been common practice to use trend modelling to predict future demand and then to modify the transport network to cater for the predicted demand. More recently, transportation policy makers and planners have started to adopt a different approach more in line with the idea that more than one group must be considered in the planning process.

This "new" approach is based, not on trends, but on "desired end states" given the current growth factors. The objective is to develop specific products which will meet the predicted demand for the generic product but which also fulfil a number of other requirements — not only those implied by current user trends but also those of the broader community.

Expanding on the above, transport is a generic product. The current trend is for increased use of the private motorcar but for many reasons, this is perceived as undesirable. Thus, an alternative transport product must be developed and marketed. The alternative product must meet the expected demand for travel but not necessarily follow current trends in terms of means of travel. The process of changing the system must of course take place over a sensible period and within the framework of existing conditions. There is however, a need to make a start with current conditions.

The most common method of transportation system design is that using network modelling, usually with the aid of computerised network models supported by the knowledge of local specialist planners. There are many different computer models available for various aspects and levels of planning. For any particular level, the models are similar in their general principles although they may differ in the detail of their operation. In South Africa, and many other parts of the world, a network-modelling package commonly used for metropolitan level transport planning is Emme/2, produced by INRO Consultants Inc. (INRO 1999.) The design process described here uses this package.

The process is adaptable to most other similar packages and may in fact give better results using a simulation model such as TRANSIMS (TRANSIMS 1995.) Other software packages may handle certain aspects of the proposed process in a better way than Emme/2 but in general, the benefits of using Emme/2 are believed to outweigh the drawbacks, in the South African situation at least. These benefits arise from two main factors:

- Emme/2 is the software most familiar to South African transport planners. Thus, little learning time is required for the implementation of the proposed public transport planning technique, which supports current political objectives.
- The models are already available and there is no need to spend money on new software and model conversion.

The rest of this chapter describes the transport network modelling process using the Emme/2 program, and how it can be used to develop potential public transport routes in a multi-modal, customer service oriented environment. The process is depicted schematically in Figure 4-1.

Key to the discussion is the understanding of a few of the basic network modelling terms employed in Emme/2. For those readers unfamiliar with the terminology, APPENDIX C provides a glossary of terms relevant to this dissertation.

4.2 EQUILIBRIUM ASSIGNMENT

Although not the only method in use[2], a common form of network modelling is that based on the principle of user equilibrium. The bulk of this chapter is devoted to a description of how the equilibrium assignment process can be used to design a multi-modal route network for a public transport system. It is thus considered necessary to provide some discussion of the key concept, that of generalised-cost equilibrium assignment here rather than in the appendices although some additional details are provided in APPENDIX D.

The equilibrium concept, due to Wardrop (1952) (From Papacostas & Prevedouros (1993)) essentially states that:

- On any network, users choose the route which minimises their own travel time and, on a congested network;
- Users distribute themselves on the network in such a way that the average travel time for all users is equal on each active route between origin-destination pairs.

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[2] See Ortúzar and Willumsen (1990), pg. 297 et seq. for a discussion of alternative assignment methods.

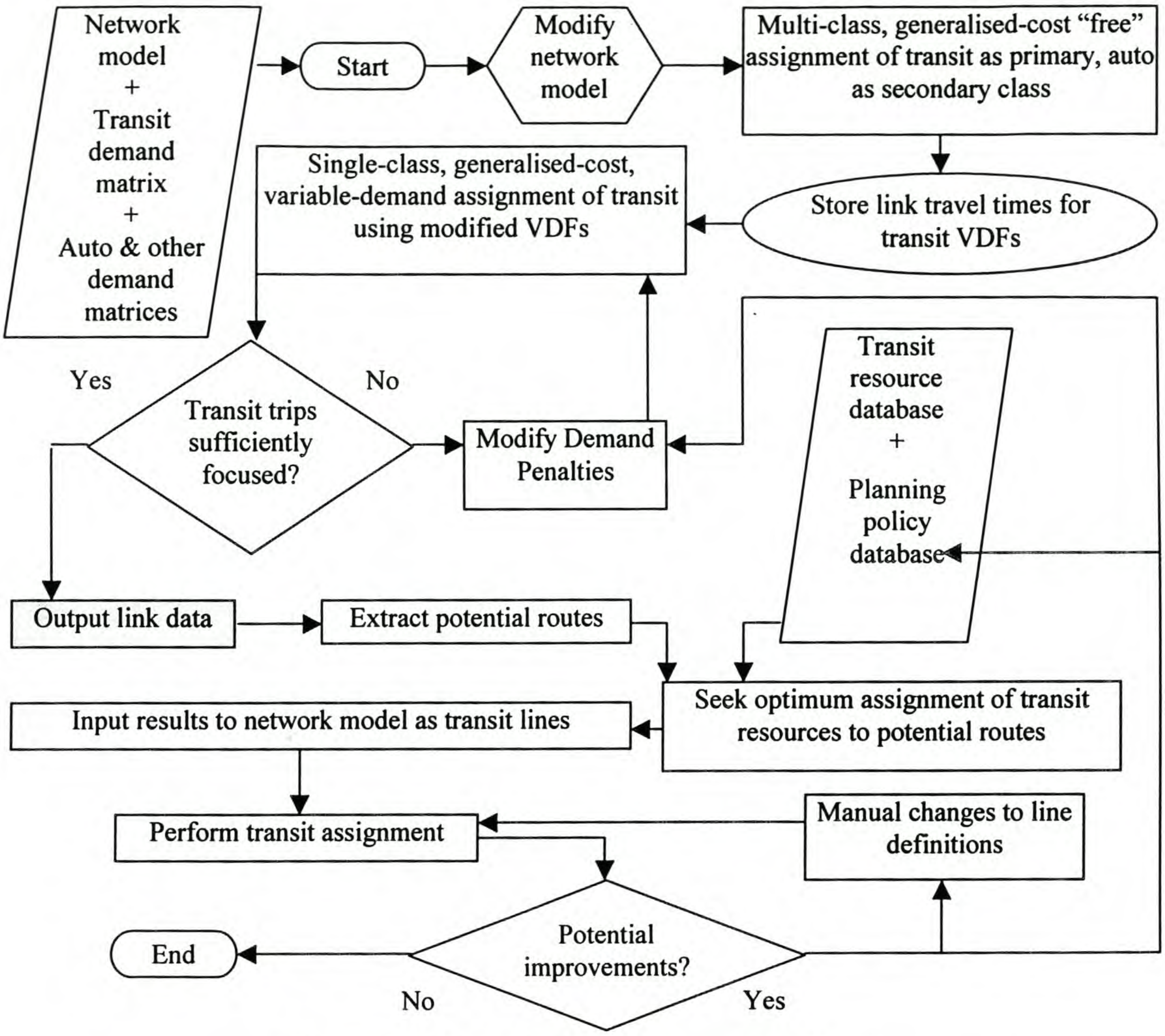

Figure 4-1: Network design process flowchart.

(Shaded elements are included in this chapter.)

A more general statement of the equilibrium concept is that users distribute themselves on the network so as to maximise their perceived utility of travel. This utility is derived from the individual's personal value set and may include many measures. Examples are travel time as before, out-of-pocket costs, waiting time, the number of transfers, walking distances, the scenery along the route, the ability to access the chosen mode, the ability to carry goods on the chosen mode, and so on. The list is extensive, trip-purpose dependent, highly individualistic, and thus difficult to model although current research into activity-based modelling is seeking to address some of the factors. (For example, the TRANSIMS (1995) project being undertaken at Los Alamos national Laboratory, USA, seeks to introduce activity based modelling into the transport network modelling process.)

The public transport route planning method proposed in this dissertation makes use of this equilibrium modelling approach but is not concerned with the specific method of determining the equilibrium flows. There are several mathematical approaches to modelling this equilibrium and each modelling package uses its own particular formulation of the problem. Emme/2 uses the linear approximation method, which is detailed, along with other methods, in the Emme/2 User's Manual. A discussion of the advantages and disadvantages of the specific methods used by the various packages is beyond the scope of this work as is a detailed study of the assignment process itself. The Emme/2 User Manual (INRO 1999,) chapter 6, provides useful additional reading on this subject, as do many other textbooks, such as those of Ortúzar & Willumsen (1990) and Papacostas & Prevedouros (1993.)

Irrespective of the specific mathematics, the fundamental process is that of assigning the traffic onto the paths offering the lowest generalised-cost between origin-destination pairs. Speaking in time terms for simplicity, on an empty network, a traveller with knowledge of the conditions will choose the quickest path. As the number of users on this path increases, the travel time on the path also increases until it is equal to the travel time on the second shortest path. Now, additional users will split themselves between the two route choices. This process will be continued until no one can improve his or her travel time by changing route.

Generalised–cost is typically measured in terms of travel time, toll charges, waiting time, direct cost and transfer penalties. For many users, there are other factors in route choice, such as route scenery or safety, but modelling complexity usually excludes them from the process. The actual cost perceived depends on the category of user, wealthy or poor, private, or public transport user. Generalised-cost, is discussed in detail later when it is introduced as a tool for both operational and policy based route design.

The assignment process takes two main forms, single-class, and multi-class assignment. The basic equilibrium assignment process is a single-class assignment. Multi-class assignment is a more complex variant of the same process.

4.2.1 Multiclass assignment

As noted, different network users perceive the generalised-cost of using the network differently. The most relevant example of this is public transport versus private transport. Public transport users experience out of pocket fare payment, low travel speeds, waiting times, transfers, and usually have to walk to and from the access points. Private car users on the other hand will experience a better travel speed, no waiting time or transfers and less walking in most cases. They will however experience parking costs, tolls, and other costs that do not apply to the public transport users, such as fuel and maintenance costs. When different user groups or classes as they are known in Emme/2, use the network simultaneously, their respective use of the network impacts the other classes. The common attribute is the travel time on the individual links. (From the Emme/2 User's manual, page 4-363, "Combining several features of the auto assignment.")

> The multiclass assignment is a true equilibrium assignment in which several classes of users perceive or use the network differently. Each user class has access to a sub network of the auto network. All classes that are allowed to use a given link perceive the same time (which is based on the combined volume on the link). However, in a multiclass assignment with generalised-cost, the additional fixed cost perceived by each class may be different.

The multiclass assignment can be used to model a variety of situations, including traffic restrictions on heavy traffic and HOV (High Occupancy Vehicle) lanes: (See Module 5.11, Example 1.6 on page 4-392 of the Emme/2 User's Manual.)

Classes are defined in Emme/2 by creating what are termed "auxiliary auto" modes. The auto mode is the "primary" mode whilst all other modes are "secondary" modes. An auxiliary auto mode may represent heavy vehicle traffic, high occupancy vehicles, or any other identifiable group of network users. Public transport users are usually not modelled in this way but are assigned to the network separately. This is done using a generalised-cost assignment approach but based on the pre-definition of public transport routes and vehicle capacities, travel speeds and frequencies. The problem is of course that one has to have this information before the assignment can be performed. The process described in this chapter is one that develops these public transport routes by treating public transport as the primary, or auto mode in a multi-class generalised-cost assignment process.

4.3 PREPARING THE NETWORK MODEL

Large urban regions are usually modelled on an aggregate basis when planning regional transport facilities. More localised and refined models are then developed for localised planning. This poses a problem for public transport planning, which needs to be region wide, whilst having sufficient detail to cover local trips in the planning process. This may necessitate the development of network models with more, smaller zones than previously.

These models are often limited to road modes. If however, an integrated, multi-modal public transport system is to be achieved, the network model for the planning of a public transport system must reflect all possible public transport facilities. These must include major pedestrian links, railway lines, ferry services and so on. High occupancy vehicle (HOV) lanes and all other conventional road facilities in the network must be available to public transport. Where minibus-taxis or perhaps even conventional taxis will form part of the fleet, it may be necessary to increase the level of detail present in the network model. It is usually sensible to try to make use of existing facilities as far as practical if cost is an important consideration. All significant interchange facilities, railway stations for example, must thus be included, by representing them as nodes connected to at least two modes so that mode changes can be modelled. The modelling process may show these facilities to be redundant or significantly under-utilised in an optimal public transport system. On the other hand, currently unused or poorly served infrastructure may prove to be key components of the optimal system.

In modelling major facilities, which might form part of a public transport system, it is important to note that the Emme/2 definition of centroids is such that trips cannot travel through a centroid although they may start and end there. If a centroid represents an actual facility, a regular node is required to model the facility. Large shopping complexes or existing interchange facilities, such as airports or railway stations should thus be modelled as separate nodes connected by a dummy link to the centroid. This will allow public transport routes to operate through, rather than only to and from, these facilities.

The approach adopted here is not standard practice and thus the network model will require other modifications than those already mentioned to accommodate the process. Aside from some general issues, a number of aspects of the model deviate from the traditional modelling approach. These are, with the relevant section number:

- The public transport demand matrix. (4.3.1)
- The average vehicle occupancy rate for the public transport vehicles. (4.3.2)
- The use of generalised-cost as a product development tool. (4.3.3)
- Volume delay functions for dedicated public transport links. (4.3.4)
- The use of a compound, empirical, fixed-cost in the generalised-cost. (4.3.5)
- The creation of a “Policy Attribute” for each network link. (4.3.6)
- The mode definitions used in the modelling process. (4.3.7)

4.3.1 The public transport demand matrix

4.3.1.1 Designing for target public transport demand levels

One of the objectives of the decision support system is to promote strategic logistics objectives. One of these objectives, in the South African case at least, is the achievement of an 80:20 public to private transport ratio. Used on a general basis, this is not a particularly useful goal. Some areas will be best off with a 0:100 ratio and others perhaps with a 95:5 ratio. The actual ratio must depend on the nature of the trips and the people making them.

A more rational method for tackling this than a blanket target value, which does not allow for structured system development, is to base the system design on a demand matrix that reflects an increased percentage of total trips made by public transport for each zone pair. Where there is only private demand, the increase is a percentage of the private trips. Ideally, the increase should be based on door-to-door market research, rather than on current user numbers. In this way, although the existing network still has an impact on the process by virtue of perceptions, it does not limit it.

Using this approach, the resulting trip assignment will overestimate the actual demand on the network. However, as will be seen in the next chapter, routes will only be extended once the demand reaches some target minimum. This will usually result in increased line lengths, and sometimes additional lines, and allows the system to be gradually built up, always providing a margin for demand growth without gross oversupply of public transport services with the associated costs.

4.3.1.2 Multi-period design considerations

It is common network modelling practice to use the AM-Peak hour as the basis of all design. Public transport systems however, usually have a number of distinct operating periods, AM-peak, PM-peak, Day-off-peak, Night-off-peak, and so on. Each of these periods needs to be modelled separately and in full. Public transport operating periods are invariably longer than one hour and are the basis of the resource allocation process. The one-hour AM-peak design period is practical for conventional traffic-network design but poses a difficulty when examining public transport if the demand for public transport is not uniformly distributed over the operating period. Firstly, the network design hour may not coincide with the peak demand for public transport in which case the true peak demand may not be correctly determined. This is aggravated by the fact that demand between different origin-destination pairs may peak at quite different times. Secondly, the demand matrices used to perform the network analysis do not provide a true reflection of the total demand for public transport over the entire operating period. The actual passenger kilometres travelled will thus be incorrect, which poses difficulty in the resource allocation process.

If the demand for public transport is uniformly distributed across the operating period, then these problems can be easily eliminated. This is achieved by carrying out the design-hour assignment with a one-hour demand matrix and then carrying out the public-transport route design with the full public transport demand matrix. The travel times will be based on the peak network load conditions and the peak public-transport demand and the total passenger-kilometres will be correct. If the public transport demand is not more or less uniformly distributed, an alternative approach is required.

Although it clearly must reduce the accuracy of the design process, the most practical way of overcoming the problem is to determine two matrices for the public transport demand associated with each temporal network model. One matrix defines the peak demand hour for the public transport system as closely as possible. This matrix is used in the network design model, even if there is not a perfect match of times. This will produce conservative results, with respect to travel times, in the network modelling process. This matrix is also used to perform the route design to ensure matching the peak demand in the rest of the design process.

The second matrix defines the demand for the full operating period of the public transport system. A scalar multiplier is then found which minimises the differences between the full operating period matrix and the design hour matrix multiplied by the scalar value. This scalar can be used as a multiplier to approximate the total passenger-kilometres on the public transport routes for the operating period.

The simplest way to find this multiplier is to use the Emme/2 program. Using the matrix calculator, the average value for each of the matrices is found. The operating-period matrix average is then divided by the peak-hour matrix average. If the public transport demand is uniformly distributed over the operating period, then the multiplier will have a value equal to the length of the operating period in hours. At the same time, the minimum and maximum values arising from the Emme/2 matrix calculation,

Operating period demand matrix – Peak demand matrix * Multiplier

will tend to zero.

The planner will have to evaluate the public transport demand data and decide on the approach to be applied. The chosen approach must then be kept in mind in carrying out the network modelling, selecting the correct matrices for the various assignment processes, and the resource allocation, where the multiplier must be correctly given.

4.3.2 Vehicle occupancy

The travel time on a network link, and thus the assignment process, is a function of the link capacity and the number of passenger car equivalent vehicles using the link. The number of passenger vehicles is dependent on the number of people travelling and the average vehicle occupancy rate. For car travel, the average occupancy rate is often determined on an origin-destination basis. In a multi-modal transit system, there is no standard vehicle occupancy for transit vehicles. If commuters are required to transfer, they may make their trip using physically different vehicles on route segments with quite different characteristics. Non-transferring trips may be made in vehicles that provide service on a longer route. In either event, the vehicle occupancy rate is link based, not origin-destination based, except possibly on express routes. It is thus necessary to use a global vehicle occupancy rate for transit vehicles.

Along with the issue of vehicle occupancy, goes the concept of passenger car equivalence. Many different vehicle types use, and interact on, a road network, each having its own characteristics. It is common practice to use the motorcar as the basic unit and then to evaluate other vehicles as multiples of that unit. Network models are usually calibrated on this basis. Thus, a small bus or truck may be considered the equivalent of two cars in terms of the influence it has on the surrounding traffic.

It is clear that a bus has more impact on the traffic flow than a motorcar. What is not clear is how much of an impact. In general, lower acceleration rates and increased length will impact on gap acceptance and speed in negotiating intersections and turning movements. The problem with setting a standard approximation is that the influence differs considerably according to the road link characteristics, as discussed by Branston (1975). For example, on steep hills with narrow streets and streetside parking, the bus may have a very high impact. On the other hand, in a freeway situation, the impact may be negligible, perhaps as low as 1.6 cars. Passenger-car equivalence values of between 1.6 and 6.5 are given for buses on two lane roads of different terrain types and levels of service (TRB 1985.)

In order to provide an estimate of the impact of the public transport trips on the road network performance it is important to ensure that a suitable vehicle occupancy rate is used. This occupancy rate needs to provide a reasonable estimate of the number of equivalent passenger cars required to meet the road based public transport demand. This occupancy rate is not applicable to the non-road modes in terms of their performance but is applied globally by the modelling process and this must be taken into account when modelling non-road modes. This is discussed later. The following approach to providing a global vehicle occupancy rate for public transport is used.

Given the prevalence of the mini-bus taxi in South Africa, this vehicle is chosen as the basis for estimating average vehicle occupancy. Assuming the 14-seat mini-bus taxi to have a passenger car equivalent of about 1, based on its general performance and size characteristics, a vehicle occupancy rate of 14 passengers per vehicle is applicable. Concurrently with the previously mentioned performance factors, increased passenger numbers increase the number of stops and boardings and alightings. It can thus be expected that the interference between public transport vehicles and other traffic will increase as the carrying capacity of the vehicle increases. Consequently, the 4.3 passenger-car equivalence of a bus carrying 60 passengers, resulting from the 14-passenger occupancy rate, seems acceptable. The fact that the reported impact is theoretically much less on freeways than on narrow, hilly urban streets is not considered highly relevant for a number of reasons:

- The proportion of public transport vehicles is usually relatively low, compared with that of private vehicles other than on certain primary public transport routes.
- In South Africa, the maximum speed limit for public transport vehicles is 100 kilometres per hour as compared to the freeway speed limit of 120 km/hr. This means that in fact the public transport vehicles have a larger impact than when free to operate at the same speed as the rest of the traffic.
- Freeways are not ideal as public transport routes due to accessibility.

Of course, the planner is free to develop a more accurate model for local conditions.

Whilst not perfect, this provides some approximation of the impact of the public transport demand on the transport-network link travel times. This differs from the approach of Elgar and Kfir (1992) who used a multiple of the travel time arising from the private traffic, irrespective of the public transport demand.

The assignment of the private traffic as a secondary class also requires another modification of the model with respect to vehicle occupancy. The Emme/2 model does not cater for a vehicle occupancy other than in the primary class and thus the auto demand would be assigned as one vehicle per person. This may produce unrealistic results. This problem is eliminated by creating a new private transport demand matrix derived from the original private demand and vehicle occupancy matrices. This is done by dividing the demand matrix by the vehicle occupancy matrix. The revised private travel demand matrix is then used in the subsequent multi-class assignments.

4.3.3 Generalised-cost

Generalised-cost is a measure of the total cost of travelling which influences route choice. Ortúzar and Willumsen (1994) point out that it is recognised that most users might wish to minimise a combination of link attributes including time and distance. The model presented by them has the form:

Equation 4-1

$$C_a = \alpha(Travel\ Time)_a + \beta(Link\ distance)_a$$

Where: C_a, the cost on link a, is measured in generalised-cost or time terms. The authors point out that the calibration parameters are extremely difficult to establish.

In a multi-modal, public transport environment, excepting walk mode links, travel time and link distance are not adequate descriptors of generalised-cost. Motorised mode links will be perceived and perform differently to non-motorised mode links. The link distance may thus have a greater weight on a walk link than on a bus link but is little influenced by demand and not at all affected by service frequency and waiting time. For walk-mode links, Equation 4-1 will be applicable and the travel time will depend on the link length and the average walking speed.

For the motorised mode links however, waiting time is important and there may be fare differences between modes. The link-based generalised-cost should thus be of the form:

Equation 4-2

$$C_a = \alpha(Travel\ time)_a + \beta(Waiting\ time)_a + \gamma(Fare)_a + \ldots$$

Ideally, elements such as comfort, safety, and other pertinent factors should also be included. Unfortunately, this form is not practicable since we cannot calibrate and model many of the variables and waiting time cannot be modelled at the link level using conventional techniques.

Simplified versions are thus used in the network modelling process. In particular, the Emme/2 model measures generalised-cost as:

Equation 4-3

$$\text{Generalised-cost} = \text{Link travel time} + \text{Weight} * \text{Fixed link cost}$$

The link travel time is determined by means of a volume delay function, which is based on the link characteristics and the number of passenger car equivalent vehicles using the link. (Volume delay functions will be discussed in more detail in a later section.) In Emme/2, the fixed link cost is a constant, stored as a link attribute. This may be the length attribute as proposed by Ortúzar and Willumsen but will more commonly be a compound value.

Public transport users and operators alike will seek to minimise the total generalised-cost experienced. On an uncongested network, this may result in the selection of a road-based route available to all network users. A small increase in the number of trips being made on the network may alter the optimal choice for public transport users to network links not available to private transport users. Thus, the influence of private traffic on the total network travel time can impact on the modal choice of users or encourage them to use special facilities, which are not necessarily user-optimal in free flow conditions.

In the public transport modelling process, the generalised-cost has a number of functions:

- To reflect any differences in the fare cost of travelling by different modes of public transport and thus of developing some level of modal split where differentiated fares are used.
- As a mechanism for identifying class volumes in multi-class assignment. By ensuring that the public transport selects the links offering the shortest physical path from several alternative paths offering equal travel time, it is possible to determine which paths are used by the class.
- As a modelling device for designing products which promote strategic goals as well as optimising more immediate operational considerations.

In respect of the above, we need to remodel the generalised-cost. The modification needs to reflect both operational and strategic conditions. The operational conditions include the fact that as demand for a public transport service increases so does the level of service, within capacity limits and that below a certain demand level, service cannot be economically provided. The strategic issues relate to encouragement or discouragement of certain routes for reasons of security, urban planning or social or economic development. In order to deal with these extra requirements, a modified generalised-cost function is proposed:

Equation 4-4

$$C = Travel\ time + Weight * \left(Link\ length * \frac{Fare}{Value\ of\ time} + Demand\ \ penalty + Policy\ \ factor \right)$$

It may be argued that this does not represent reality and is difficult to calibrate. Since we are using a backward seeking modelling approach, this is not important providing that care is taken to avoid one element dominating the result. For example, if we wish to ensure the use of the shortest path, including even a small link length component into the cost will achieve the desired result by favouring the shorter of two equal time paths. We could thus use a weight that limits the length component to about 10% of the link travel times.

The demand penalty is used in the focusing process and will be discussed in more detail later. Its main function is to implement a penalty related to the demand on a link and the balance in demand between the two directions of a link pair. This penalty is a function of demand and essentially reflects sustainable service frequency. The reduced frequency resulting from low total demand or strong directionality shows up to the user in the modelling process as an additional cost.

The policy factor is somewhat less precise in its use and is implemented early in the design process. A typical use of the policy factor may be to discourage road based public transport adjacent and parallel to an existing rail service by implementing a cost penalty for such a service within 500m of the railway line. Other examples may be where a corridor development is proposed and is to be supported by some special subsidy or where a public service facility, a school, or hospital, is to be on a route irrespective of demand.

Every link will have a fixed-cost determined in the same manner and thus, since the cost is only applied within one class, the absolute value is not as important as the relative values from link to link. Nevertheless, the weighting factor and the fixed-cost must be carefully determined in order to avoid biased model results in which either travel time or the fixed-cost dominates the assignment process.

Both the volume delay functions and the fixed cost will be discussed in more detail in following sections.

4.3.4 Volume delay functions

The generalised-cost equilibrium assignment process described earlier requires a mathematical model describing the travel time on each link and through each intersection as a function of the number of vehicles using the link or intersection. These functions, known as volume delay functions, may take one of several forms, the most common being the BPR (Bureau of Public Roads) model (Branston 1975 "Link Capacity Functions",) shown in its simplest form in Equation 4-5.

Equation 4-5

$$t(v) = t_0 \cdot \left(1 + \left(\frac{v}{c}\right)^{\alpha}\right)$$

Where:

t = Actual travel time on link.

t_0 = Minimum travel time on link.

v = Vehicle volume on link.

c = Vehicle capacity of link.

α = Calibration parameter.

The calibration parameter is determined from traffic flow studies of the various link types being modelled. (The equations are often somewhat more complex and include more than one parameter.) For the purpose of this study, the exact nature and form of the volume delay functions is not important as it is assumed that the general transport network model already exists. There are however, links which will not have such functions in a normal transport model but that will require them for the public transport planning process.

On the regular road links, the volume delay functions will be unchanged in the public transport modelling process. The average vehicle occupancy proposed for the vehicles will convert the number of person trips to an approximation of the public transport vehicle impact on travel time and thus equilibrium distribution of traffic. On road links not available to private traffic, dedicated bus lanes for example, and railway lines, such volume delay functions will not be included in the conventional model. It is however necessary for such functions to be developed. These volume delay functions should reflect the travel time in the same way as conventional road links but must allow for the fact that, especially on railway, the travel time is little affected by demand below the mode capacity. This means that the travel time is constant up to capacity but may then rise quite sharply. Where a BPR type volume delay function is applied, the use of a high value of α may be expected.

In developing these volume delay functions, it is also important to take into account the average vehicle occupancy rate that will be applied by the model. For example, if an occupancy rate of 14 people per vehicle is used, and a railway line sees a demand of 6000 people, then Emme/2 will set v as 6000/14 = 429. At the same time, if the line has a capacity of 10 000 people, then c must be entered as 10 000/14 = 714.

This volume delay function is a very rough approximation of reality for two reasons:

- These functions are required to be strictly non-decreasing. This is something of a problem in public transport where there is generally a reduction in overall trip time as the demand increases, justifying increased service frequency.
- Passengers are only required to wait at their point of boarding, not at subsequent links and thus, waiting time cannot be included in a link function. Similarly, transfers are not link-based, occurring as they do at nodes. Where the waiting times for intermodal transfers are considered relevant, dummy links connecting the rest of the network to the access nodes can be used to simulate the relevant cost. A typical example of this occurs where a road based feeder links to a railway service. A transfer is known to occur and it is possible that the headway between trains is significantly longer than that feasible on the road network for some reason. This being the case, some measure of this can be included in the dummy link.

Theoretically, this technique could be applied to all public transport mode access points but this would require very extensive model changes. The main objective is to achieve a relative travel time for each available mode since all public transport modes have some waiting time penalty as against the auto mode.

4.3.5 Fixed-cost

The second component of the generalised-cost, discussed earlier, is the fixed cost component. The use of a fixed cost as a design tool has the particular advantage of ensuring that no transport element is ever totally removed from the options available. The element may become exceedingly expensive to use but it remains available. It is thus possible to determine when it would be used in spite of the high cost. If in fact, it is used, then a need exists that is not satisfied by any alternative and a policy rethink may be required. This in turn may lead to significant changes in the whole system design. The entire process is greatly simplified by using penalties rather than adding and removing network elements in successive exercises.

In Equation 4-4, the fixed cost was split into three components that will be examined in detail:

- A distance-based cost (fare)
- A demand penalty
- A policy factor

Each of these elements must be saved as a separate link attribute as one or more of them may change during the design process and a revised value for the fixed cost must be determined several times.

4.3.5.1 The fare-based fixed-cost component.

We are creating a market-oriented service; therefore, the fare and thus the operating cost of the service must be taken into account. The actual operating cost on each route will depend on the mode and vehicles selected for the task but users will perceive only the fare. Consequently, an average fare-per-kilometre for each main mode is used. Measuring the fixed link cost in terms of average link fare enables the inclusion of inter-modal fare differences in the model and incorporates path length into the route choice decision.

The use of an average fare is sensible in the SLM model because the different routes are only able to operate in conjunction with each other. Several feeders with relatively high costs may be necessary to make a high volume service with relatively low costs viable. There must be some cross-subsidisation of routes if the goal of maximised public transport usage is to be achieved.

As already noted, the Emme/2 model does not allow a travel time weight in the generalised-cost and thus the fixed-cost should be measured in terms of time to be meaningful. This is achieved by using the perceived value of time of the users to convert the distance-based fare into a time value. The establishment of the particular value of time to be used is beyond the scope of this study but for the purpose demonstrating the concepts a mini-survey was carried out, eliciting values of time ranging from R 30 per hour to R 12 per hour with a tendency towards the lower number. This data has been used on the assumption that most public transport users are employed, can afford to pay the fare, and have a perceived value of time.

For some, the value of time will be much higher; these people are unlikely to be willing to use public transport under any circumstances. On the other hand, some users of public transport will be unemployed and for them, the value of time is very low. These people do not however need to travel during peak hours and are hopefully a minority group.

The determination of the fare-based fixed-cost component is demonstrated in an example where a value of time of R 12 per hour is used:

Assume two routes between A and B, one bus and one rail with the attributes shown in Table 4-1:

	Bus	Train
Fare per km	R 0.50 /km	R 0.30 /km
Km	20 km	31 km
Travel time	40 min	41 min

Table 4-1: Route – Vehicle attributes demonstrating fare component of fixed cost.

From these attributes, it can be seen that the values shown in Table 4-2 apply for the alternative routes between A and B:

	Fare	Travel time
Bus	R 10	40 min
Train	R 9.30	41 min

Table 4-2: Fare and travel time for different routes and vehicles.

Setting the value of time as R 12.00 per hour, the time value of a Rand is 5 minutes. Thus, the total time value of travelling by bus is 40 + R10 * 5 = 90 minutes, and for train is 41 + R 9.30 * 5 = 87.5 minutes. Assuming that the value of time will be included in the link attribute then, in the example, the additional cost (AC) for a link will be:

$$
\begin{aligned}
AC_{link} &= \text{Length} * \text{fare per km} * \text{time value of a Rand} \\
&= \text{km} * \text{Rand/km} * \text{minutes/Rand} = \text{minutes}
\end{aligned}
$$

This gives:

For a bus link: $AC_{bus} = \text{length} * 0.5 * 5 = \text{length} * 2.5$

And for rail: $AC_{rail} = \text{length} * 0.3 * 5 = \text{length} * 1.5$

A possible enhancement lies in the use of a demand dependent fare structure. Over a certain level of demand, larger vehicles are cheaper per passenger-kilometre to operate than smaller vehicles. Thus, a differentiated fare system could be modelled. This can be implemented using the same process as described for the demand penalty component of the fixed-cost. The step in the fare-based cost will be associated with the change-over from one vehicle type to the next. The concept is described in the chapter on route extraction where links are separated into demand categories matching certain classes of vehicle.

The author has heard it stated that the value of time is not a useful measure. It is however, the most logical measure available and the crucial issue is not so much the actual value as the relative cost of the different modes and the incorporation of a distance element into the route choice process. Given the uncertainty in the value of time as well as in the possibility that the fare will change during the design process, it is suggested that, even though not theoretically correct, this component of the fixed cost be given a fractional weighting. In the case study, a weight of 0.1 has been used. This gives dominance to the travel time factor but since, as pointed out by Lampkin & Saalmans (1967) the operating costs are usually more time than distance dependent, this seems reasonable. (Refinement of the calculation may be justified, given that the fare usually comprises boarding, time-based and distance-based components.)

Determining the value of time is the most difficult part of this task, being zone dependent to some extent. However, since the zone-based value of time cannot be used in a link-based volume delay function, an average value for those typically using public transport should be used. Stated preference techniques provide a suitable mechanism for obtaining such data, as has been demonstrated by Pearmain et al (1991.)

4.3.5.2 The demand penalty component of fixed-cost – Single operating period.

In the design of public transport routes, one of the biggest problems is that the diversity of trips is such that they cannot be satisfied individually. The planner must seek to achieve a compromise between customer needs and a sustainable public transport system. It is proposed that this is done using a focusing process in which customers are "encouraged" to travel in groups to support more obscure origin-destination pairs although along the way they may change the group with which they travel.

There are two considerations in the practical focusing process. Firstly, the focusing should occur in relatively small steps, as marginal routes may become viable with the addition of just a few trips from another less viable route. Larger steps may eliminate the marginal route too early in the process thus eliminating the most attractive and realistic route option for users in the area. Secondly, routes with a large total number of trips are preferable to routes with fewer total trips but not to routes with the same total number of trips more evenly balanced in the two directions.

The step size on a small system may be arbitrarily chosen at one or two trips. This can be somewhat time consuming in a large system however and instead, the minimum viable load on the smallest available vehicle serving the mode is used as the step size. For example, where minibus taxis are used, a minimum load of 12 may be considered necessary for viability. (There are even smaller public transport vehicles operating successfully in the Cape Metropolitan Area.) Step sizes of 12 passengers are thus used in the focusing process. Selecting the links that are to be favoured in terms of balanced demand is achieved by using a ranking process which rates the links in accordance with the demand on the link and the demand on the reverse link, both with respect to the minimum step size. Modelling this process can be achieved as follows:

For each link, a link index (LI) is defined as:

Equation 4-6

$$LI = f(\mathrm{Vol}_{ij}, \mathrm{Vol}_{ji}, \mathrm{MinDem.})$$

Where: Vol_{ij} = Trip volume on link from i→j

Vol_{ji} = Trip volume on link from j→i

MinDem = Minimum demand which will sustain a service.

The general form for determining LI is:

Equation 4-7

$$LI = a + \sum_{f=1}^{f=F} \left[b_1 \cdot \delta\left(h_o * Vol_{ij} \geq \left(f \cdot MinDem\right)\right) + b_2 \cdot \delta\left(h_o * Vol_{ji} \geq \left(f \cdot MinDem\right)\right) \right]$$

Where: a = Parameter setting the minimum value of the index. Must be > 0.

$b_{1,2}$ = Parameters reflecting the relevant importance of the two directions. Usually equal at 0.5. Different emphasis could be achieved by changing the relative values of b1 and b2.

f = Step counter and vehicle frequency.

F = The current level of focusing. Maximum value should be around target frequency.

$MinDem$ = The minimum demand to justify one trip of the smallest available transit vehicle of the mode.

h_o = An optional factor = Operating period average hourly demand / Design hour demand.

$Vol_{ij,\, ji}$ = Link volumes in direction i→j and j→i respectively.

δ = Function returns 1 if relational operator evaluation is true and 0 if evaluation is false. See following Note.

(Note: The author has found no standard form for writing this and has used a notation derived from the Kronecker Delta function. The Floor function, symbolically written using floor brackets $\lfloor \; \rfloor$ can be used to produce a similar, but not identical, result. It does not however accurately represent the actual process occurring in the Emme/2 modelling package.)

The inclusion of the value h_o arises from the problem of design-hour versus operating period demand assignment when the operating period and design period are of different lengths, which they usually are and when more than one operating period is being considered. A long operating period with a low but steady demand may provide better route choice options than an operating period with a higher peak period demand but little or no demand over the remainder of the operating period. If the operating period average hourly demand and the design hour demand are the same, h_o will equal one. If the design hour demand is high and the operating period average hourly demand is low, h_o will tend to zero, forcing a higher design period demand for acceptance as a route. Since h_o is an average value for the system, it should be used with caution as it may be contrary to the actual circumstances on some links. The value h_o is also used in the resource allocation process.

Equation 4-7 is demonstrated in the following example where b_1 and b_2 are equal at 0.5 and assuming a minimum economic demand of 12. $h_o = 1$ for the example. Vol_{ij} and Vol_{ji} are replaced in the example by the Emme/2 words volau and volaur respectively:

Link Index =	Step No.
0.1	(f) – Minimum frequency.
+0.5*(volau ≥ 12) + 0.5*(volaur ≥ 12)	1
+0.5*(volau ≥ 24) + 0.5*(volaur ≥ 24)	2
+0.5*(volau ≥ 36) + 0.5*(volaur ≥ 36)	3
+0.5*(volau ≥ 48) + 0.5*(volaur ≥ 48)	4
+0.5*(volau ≥ 60) + 0.5*(volaur ≥ 60)	5
+0.5*(volau ≥ 72) + 0.5*(volaur ≥ 72)	6
+0.5*(volau ≥ 84) + 0.5*(volaur ≥ 84)	7
+0.5*(volau ≥ 96) + 0.5*(volaur ≥ 96)	8
+0.5*(volau ≥ 108) + 0.5*(volaur ≥ 108)	9 (F) Policy frequency.

Using the link index determined above, a demand penalty (DP) is determined for each link carrying motorised traffic. (Walk mode links are not subject to a demand penalty. These links are excluded by using the mode definitions.) This is an empirical value and is evaluated as:

Equation 4-8

$$DP = (MF / LI) - 0.9$$

Where: MF = **M**aximum **F**requency which can be sustained by the demand on the link. This is the same as the current step number (f) given in the example above.

LI = Link Index. See section 4.3.5.3 for temporal considerations.

0.9* = A correction factor to set the minimum penalty as close to zero as possible.

*(Strictly speaking, a function of the value of the minimum link index value *a*.)

When variable demand functions are used, it may be necessary to reconsider the value of $b_{1,2}$ (values other than 0.5) in Equation 4-7 so as to achieve a demand penalty more in line with the demand elasticity with respect to service frequency, (or waiting time.) This may require modification of the demand penalty equation, Equation 4-8 as well. Since the form of the demand function is model specific, this is not discussed further in this chapter.

This formula gives rise, in the fourth step, to results similar to those shown in Table 4-3.

Col 1	Col 2	Col 3	Col 4	Col 5
Volau ≥	**Volaur ≥**	**Link index**	**Step (Freq.)**	**Demand Penalty = (Max(Col 4) / Col 3) – 0.9**
0	0	0.1	1	39.10
12	0	0.6	1	5.77
12	12	1.1	1	2.74
24	0	1.1	2	2.74
24	12	1.6	2	1.60
24	24	2.1	2	1.00
36	0	1.6	3	1.60
36	12	2.1	3	1.00
36	24	2.6	3	0.64
36	36	3.1	3	0.39
48	0	2.1	4	1.00
48	12	2.6	4	0.64
48	24	3.1	4	0.39
48	36	3.6	4	0.21
48	48	4.1	4	0.08

Table 4-3: Link Index and Demand Penalty. Example values.

In this example, once the demand reaches at least 48 trips in each direction, the demand penalty becomes very small. Of course, if the smallest vehicle carries 25 people, then the formula will change to reflect multiples of 25 instead of 12. With each iteration, the penalty for very low volumes is increased, so in the next step, after that shown in the table, the penalty for there being less than 12 trips in either direction becomes 49.05 units.

When there are a number of parallel links, each carrying only a few trips, all are penalised. Since, within the model, the travellers will still make the trip and will choose the shortest path, the demand penalty will reduce on some links as the focusing process proceeds.

The increasing cost with reduced demand arising from the demand penalty is realistic in the public transport environment where it occurs, either as a high fare, or as a long headway. Where there are no alternative routes, users must pay the higher cost, forego the trip, or change mode. Where alternative routes do exist, users will choose the more heavily utilised, and thus "cheaper," routes providing that the ultimate cost of doing so is to their benefit. Using this iterative approach will tend to provide a more realistic set of route choices than the alternative of using one step in which a heavy penalty is applied to all links carrying less than say twenty-five trips.

One is tempted to use the minimum sustainable headway as the demand penalty. This is however not realistic for two reasons:

- The headway dependent waiting time is not associated with each link.
- In a commuter situation, users are aware of the departure time of their vehicle and so arrive at some fixed time before its departure. They may thus only wait a few minutes, even with long headways.

This process approximates the relative time and monetary cost of route choice — reduced frequency imposes time penalties with a zero service frequency equating to the necessity for a private car or taxi with the associated costs. On unbalanced routes, users will have to pay the higher fare (in theory) necessary to cover operating costs for the poorly utilised direction. It is also important to note that the penalty is applied to every link and so is additive for a trip. Users will thus attempt to join busier routes as early as possible, even at low penalty rates.

The demand penalty developed up to this point effectively deals with total demand and demand balance during one operating period. Public transport demand is however, highly temporal. Further modifications are thus required.

4.3.5.3 The demand penalty component of fixed-cost – Multiple operating periods.

In all phases of the public-transport-system design process, the temporal nature of travel demand is an important consideration. The traffic patterns of AM and PM peaks are approximate but not exact "mirror" images of each other. The off-peak traffic patterns are usually significantly different. This is illustrated in Figure 4-2.

Providing different sets of public transport routes for each operating period, whilst conceivably slightly more economical for the operators, means that customers and drivers have to adjust their travel patterns both spatially and temporally during the day. It may also require additional and less utilised infrastructure. Similarly, we may wish to operate a system in which vehicle and headways differ from period to period. We need however, to limit the number of functionally different periods per day, typically - peak, day off-peak and night off-peak. There will also be functional periods for weekends and holidays.

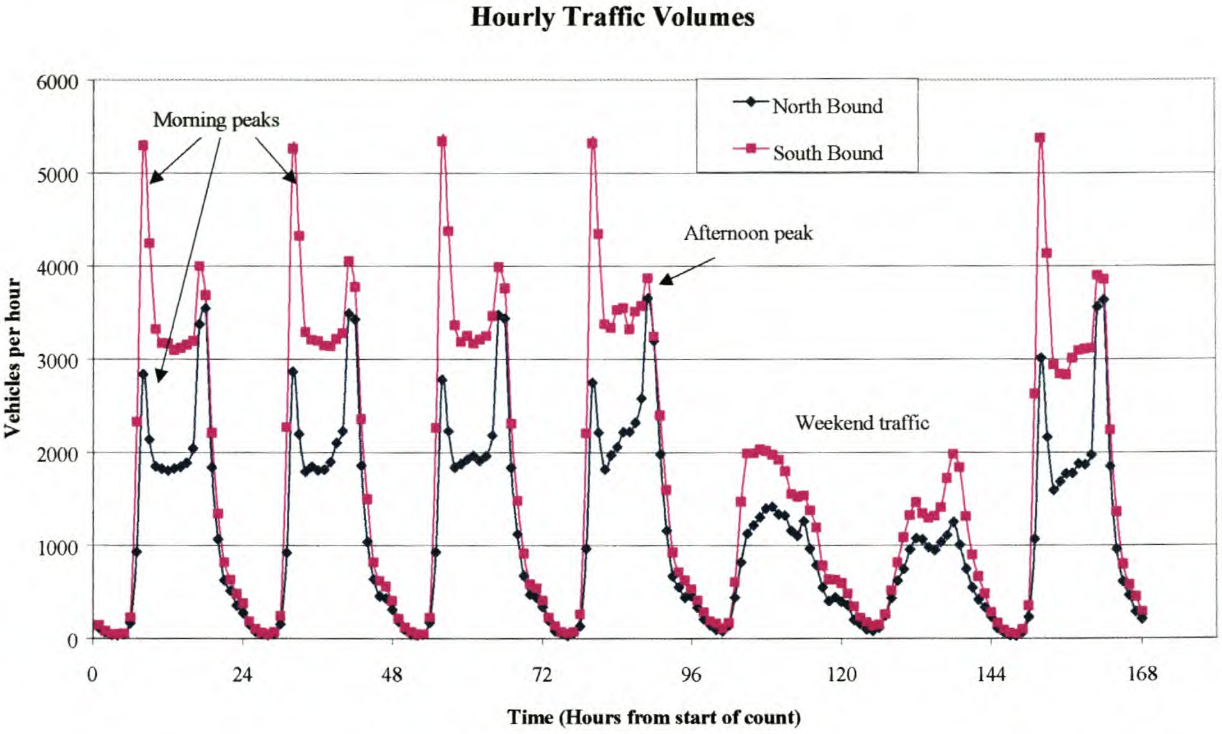

Figure 4-2: A typical urban area traffic pattern for a one-week period.

Unfortunately, there is often not full traffic data available other than for the morning peak period. Fortunately, public-transport demand data in respect of current users of the system is usually available for all periods of operation. Simultaneously, the off-peak periods are not nearly as much influenced by system congestion constraints and so public transport travel models can be developed for these periods, without excessive expense, by relying on fixed link travel times. The best quality data should be obtained as far as possible, but this can be done over a period and the use of whatever data is available will help guide the public transport system design. The evening peak is a little more difficult if complete system data is not available as congestion effects are again important. A very rough estimate of conditions might be derived by using a transpose of the morning-peak private-traffic demand-matrix, multiplied by some fraction to allow for the greater spread of the evening peak.

With such temporal models the route development process can be driven in such a way as to seek routes satisfying the daily, or even weekly, rather than peak period maximum demand patterns. This relies on a compound assignment process for which it is necessary to have a model for each operating period. This is time consuming and data intensive but can provide an improved public transport network design from the customer, operator, and local authority point of view. Customers gain through standardisation of routes and possibly, reduced operating costs. Operators are better off with a standardised route system as it is simpler to monitor and maintain. Drivers do not have to learn too many routes and deadheading can be reduced through suitable siting of depots. Finally, the local authority will maximise the use of fixed infrastructure.

Such data aggregation will naturally be biased towards one or both of the peak periods as opposed to the off-peak. The author believes however, that this is acceptable since off-peak trips are normally less time sensitive than peak period trips and thus less route-critical. The process does however take into account all trip combinations and seek to satisfy as many of these as possible.

The compound analysis is achieved by using a function of the link indices determined for each of the operational periods as the parameter for determining the demand penalty. This is based on the fact that as demand increases, so does the link index. Earlier, the impact of forward and reverse link volumes on the demand penalty was shown in Table 4-3. The same principle applies across the operating periods. Thus, a link, busy in both directions all through the day, will have the lowest penalty whilst a link with no demand at any time will have a very high penalty. Links with varying degrees of intermediate temporal demand will have proportional demand penalties. This is achieved by determining a composite link index as the geometric mean of the link indices of the different operating periods as follows:

Equation 4-9

$$CLI = \left(\prod_{n=1}^{P} LI_n \right)^{1/P}$$

Where: CLI = Composite link index.

LI_n = Link Index for period n.

P = Number of operational periods under evaluation.

Equation 4-9 reflects a bias towards customer service across all operating periods versus a focus on customer service during the peak periods, which will result from using the arithmetic mean instead. The demand penalty, DP, is then determined as before except using CLI.

Equation 4-10

$$DP = (MF / CLI)) - 0.9$$

Within the Emme/2 model, the composite link index and the demand penalty values can be determined in one scenario or databank and then copied to the other scenarios, or databanks.

4.3.5.4 Demand penalty evaluation for different modes.

The final issue to be considered with respect to the implementation of the demand penalty is the links to which it is to be applied. Demand penalties are clearly not applicable in the case of walk only links. Demand penalties may however be expected to apply to all motorised-mode links but with some possible differences between primary modes (road, rail, etc.) Where a non-road mode presents the only alternative, no focusing should be applied. A ferry across a river may be an example of this. The ferry operating criteria will then be based on other factors than just demand. Assigning different penalties to different primary modes (road, rail, etc.,) is done using the mode definitions for the network links.

Where a non-road mode operates as an alternative to road transport, the situation is somewhat different. The main factor applying to the non-road modes is that there is usually almost no opportunity for vehicle-demand matching. The non-road modes, rail for example, often have very high capacity but also many other operating parameters not applicable to the road modes. For example, if a train must be moved, given that it can only move along the official route unlike a road-based vehicle, there may be a gain in carrying any number of passengers. On the other hand, if the train can be stored where it is and operate at an acceptable utilisation later in the day, an alternative bus service may be more suitable during the interim.

The focusing criteria thus being somewhat different for different modes, what is required is a clear policy statement regarding which modes, if any, are to be favoured and to what extent. Will rail be run at any cost? Can the high capacity modes be reserved for peak periods only? The modelling process should be carried out without applying any demand penalties to the rail service whilst imposing policy and demand penalties on links that compete directly with the rail. If when the entire process is complete, the rail demand still does not justify the service and the service can be dropped, the process is repeated but this time eliminating the unsupportable rail service from the options open to travellers. Of course, if circumstances allow, for example if trains can be split, then the focusing process as applied to road modes can be applied equally to other modes although care should be taken in doing this to ensure that the process is meaningful.

Sometimes a road-mode link or set of links is to be provided with public transport more or less irrespective of the demand. In this case, these links are not penalised for low demand and some demand may gravitate to those links from other links. To implement this, these links need to be marked in some way within the model so that they can easily be excluded from the demand penalty process. Sometimes a link may be singularly undesirable as a public transport link irrespective of demand. This is best dealt with by means of a policy factor.

4.3.5.5 The policy factor component of fixed-cost.

One of the primary objectives of the strategic logistics management design process is to produce marketable and sustainable products. This is not the same as the conventional predict and provide approach to transport modelling. Current trends may not be acceptable and viable alternatives must be provided. The planner thus needs to seek some sort of compromise between the customer's perception of the ideal public transport system, the operators ability to provide financially sustainable services and the community objectives of long-term sustainability. For example, the economic development of a region may be an important social objective and a development corridor may be the means chosen to attempt the addressing of this problem. Key to the success of the corridor development will be a good transport system and planners may therefore decide that public transport should use this corridor as far as is practical and impose a penalty for using routes outside of the corridor, which could practically be served by the corridor. Similarly, schools and hospitals should be served by public transport irrespective of other considerations support must be provided in these areas when necessary to sustain the service.

Some of the factors influencing long-term sustainability are essentially non-negotiable and must therefore be modelled in some way by the planner as a set of limitations on the freedom of the public transport users in the design process. These limitations are applied in the form of a "policy factor" imposed as a "cost or reward" for choosing certain parts of the network. The fixed-cost component of the generalised-cost thus needs to incorporate a political and urban planning aspect to be used in the route design process.

Policy modelling using the fixed-cost may be implemented in one of two ways:

- As a positive or negative modification of the fixed-cost component of the generalised-cost. For example, it could be a negative percentage of the fare component or a simple cost associated with using a link.
- By explicitly not implementing other components of the fixed-cost component of the generalised-cost.

In both of the above cases, a link marker is required which is discussed in the next section and shown in Table 4-4.

This policy factor is established at the very beginning of the modelling process and remains fixed except where the policy is a function of demand. Ideally, two parallel modelling exercises are carried out. One of these incorporates the policy factors and the other does not. In this way, the impact of the policy factors can be measured and monitored throughout the process — the policy decisions may be poor ones. This does however call for adequate computer capacity.

As mentioned previously, the policy factor is based on less precise issues than the demand penalty although there may be a strong relationship between the two. The value of the factor should be a function of the link length decided upon by the planner and policy makers. Using a function of the link length will tend to maximise the distance over which the positive policy is implemented whilst minimising the distance over which negative policy is ignored by users when they have a choice of paths. Where modelling indicates that an element is required in spite of a negative policy, the cost of modifying the element to allow policy revision is minimised by virtue of its use over the shortest possible distance. An example of this is where it is considered undesirable for a series of links to be used for public transport because they are too narrow. Because of the penalty, the users will seek a wider road without the penalty as soon as possible. In this case, the penalty could be associated with the cost of increasing the width of the road

The most basic examples of possible uses for the policy factor are corridor development and prevention of duplicate services. For corridor development projects, there may be a willingness to subsidise the service on a section of the route to encourage its use. Alternatively, the frequency of service may be guaranteed, even when there is relatively low demand apparent in the design process. On the other hand, services running parallel to existing major infrastructure, such as a bus service parallel to and within easy walking distance of a railway is penalised to try to eliminate the development of the route.

The method can be used to assign penalties to links that are not to carry public transport by virtue of their link type. This is preferable to taking the links out of the model-network because there may be circumstances in which a real-network modification is justified – especially where public transport promotion is a priority. This will show up when trips are not diverted, even when a high penalty is imposed on a link or set of links.

It may be argued that the policy factor must be backed-up by practical implementation, such as fare subsidy, when the public transport system is operational. This is not really the case because the policy factor is implicitly implemented in the provision, or otherwise, of a service on a potential route and the frequency of service that is provided. It must be kept in mind that the process is intended as a design tool rather than as a prediction device.

4.3.6 Policy attributes

Since the design of a public transport system necessarily incorporates a number of political and urban planning policies that are differently applied in different areas of the network, some mechanism is required to identify the links to which particular policies apply. This is very simply achieved, (theoretically,) by creating an extra link attribute, or using one of the standard user attributes, to store a policy code that is used as the selector for the applicable fixed cost during the modelling process.

Simplicity is important if the model is to be practical to use and thus a numeric or single alphabetic character code is deemed best. The numeric code would have a structure of the form shown in Table 4-4.

Code	Meaning	Policy factor
0	No policy factor.	0
1	No demand penalty to be applied.	-DP
2	No fare penalty to be applied.	-(2.5 * link length)
3	No demand or fare penalty to be applied.	-DP -(2.5 * link length)
4	Policy factor type A to be applied.	-(0.1 * DP)
5	Etc. etc.	

Table 4-4: Typical policy factors.

The actual implementation may not be so simple in a large model where hundreds or even thousands of links have to be marked individually. This particular problem can be overcome in a network-modelling package allowing street names. In order to deal with the problem in Emme/2, the DSS database caters for street names, which can be used for other purposes as well.

Once entered into the model, all the links in a street can be called up and processed as a unit by specifying the street name.

4.3.7 Mode definitions

In the Emme/2 modelling process, auxiliary auto modes are used to specify the sub networks, of the road mode, accessible to the various user classes in a multi-class assignment. (This does not include pedestrian and non-road modes.) More than one auxiliary auto mode may be defined on each link; for all such modes, travel time is specified by the link's volume-delay function but the rest of the generalised-cost is specified by a separate link attribute.

In order to be considered in the route choice, an auxiliary auto link must also allow the primary auto mode. This is necessary to conform to the restrictions of the Emme/2 modelling package in which only the auto mode has unrestricted access to all links. From the Emme/2 User's Manual page 4-354:

> The subnetwork accessible to each class is defined either by the auto mode or by an auxiliary auto mode. Note that a subnetwork defined by an auxiliary auto mode contains only the links where both that mode and the auto mode are allowed. The demand for each class is assigned to paths that are restricted to the relevant subnetwork.

This means that in order to create a truly integrated public transport plan, public transport must be assigned as the primary auto mode, and the regular auto demand must be treated as an auxiliary mode. In this way, the rail links will allow public transport but not auto. Similarly, public transport users can walk between access points. Thus, once the network has been defined with suitable volume delay functions ascribed to all links, the mode definitions of the links need to be modified. All links, irrespective of mode, are defined as supporting the auto mode.

All conventional auto links are defined as being auxiliary auto links thus restricting the non-public transport road traffic to the road network. This allows us to assign the multi-modal public transport and regular auto traffic to the network concurrently. Public transport users have access to the entire network and can "change" mode when this improves their generalised travel cost. The modifications can be quite easily implemented in Emme/2 using a macro such as "Changemod," given on the accompanying compact disc in the folder "Emme2\Macros." Modes previously forming "Auxiliary Auto" modes are unaffected by the changes.

We now have a network model that describes the public transport and auto networks and origin-destination demand matrices. The network model and public transport demand matrices both reflect the policies of the authorities. The other demand matrices, auto and auxiliary-auto, are as for the conventional network model.

The next step is to carry out a generalised-cost, multi-class assignment, with the public transport demand as the primary class and the auto demand as the secondary class. This means that public transport users can choose any route they wish.

4.4 MULTI-CLASS ASSIGNMENT

In order to perform a free assignment of the public transport trips taking into account the impact of interaction between public and private transport modes, a multi-class, generalised-cost assignment is carried out. Actually, one such assignment is carried out for each operating period. This means that usually, the peak hour from each operating period is used. **The discussion will generally refer to one assignment period but this should be read to cover each operating period as a separate but parallel process.**

In this multi-class assignment, the primary class represents the public transport demand with a vehicle occupancy as discussed earlier. The generalised-cost is the link length, with a weight of one tenth, plus any other factors that will affect the public transport operations, such as tolling, or demand independent policy factors. The secondary class is the general auto demand reflecting the vehicle demand rather than the people demand. The generalised-cost for this class will be as it was in the original model. Any other classes, which existed in the original model, can be added in the same way.

It is possible within the Emme/2 model to extend this assignment to cater for variable demand. The demand functions used can incorporate fixed or captive demand elements along with other factors. (This is discussed in the Emme/2 Manual (1999) on page 4-355.) Where sufficient data is available, this can thus be used to evaluate routes based on need; i.e. where the bulk of the demand is captive, it is more important to provide a service than where the bulk of the demand is choice. Lacking data with which to demonstrate this possibility, only fixed demand assignment is used here.

In this process, all network users are assigned to the network concurrently and the network wide influence of the interactions can be seen. Public transport users will select the best path in time terms, always favouring the shortest distance because the generalised-cost includes the link lengths. These users will also be influenced by the policy factors. Auto users will select the shortest time path available to them given that public transport is favouring the shortest distance paths. This supports three optimisation considerations:

1) The operators will minimise their operating mileage and thus costs. (Deadhead mileage, the vehicle mileage between depot and route end, is another issue.)
2) The public transport customers will travel by the shortest distance and time, and thus cheapest path.
3) Public transport is favoured over private travel by being given preference on the "best" routes in the planning process.

The result of the assignment is the very best achievable generalised trip cost for anyone on the network, irrespective of mode, given the prevailing demand patterns. The Emme/2 model has an option for splitting the class volumes for independent evaluation. This is not necessary for the implementation of the overall public transport planning process but is a useful visualisation tool.

In order to perform this assignment and derive optimal benefit from the results, it is necessary to create two extra link attributes, one for the public transport volume on each link and one for the private transport volume. Then, the following Emme/2 steps are used:

```
5.11 Prepare scenario for assignment
        1= fixed demand auto assignment
                (Possibly necessary to ask for new assignment depending on model status.)
                5= generalized cost multiclass assignment with class specific volumes
```

When this assignment is run, the public and private transport volumes for each link are stored in the extra link attributes and can be displayed as separate volumes on the graphic output.

Having assignment results for all demand means that the planner can evaluate problems in the network arising out of public transport usage of certain links. This is most effectively used when a multi-class, generalised-cost assignment with class specific volumes is run at the very end of the modelling process, using the final fixed link costs. A graphic example of the result of this multi-class assignment using class volumes is shown in Figure 4-3. Other results are shown in the case study in Chapter 9.

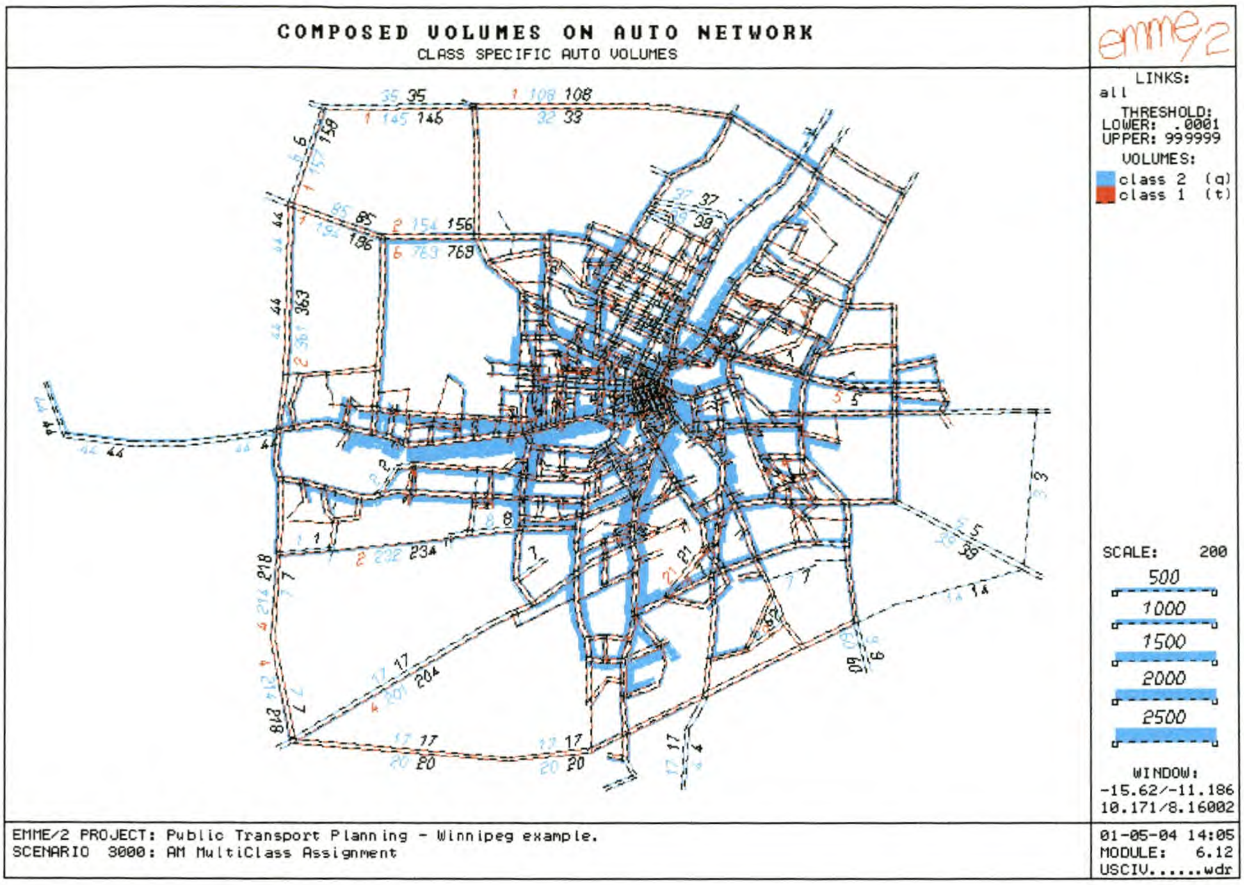

Figure 4-3: Class specific vehicle volumes arising from the multi-class assignment of private and public transport on the same network in the Winnipeg case study.

(Note: The diagram gives private (cyan), transit (red) and total (black) vehicle volumes. The number of transit vehicles is often very low and sometimes, the Emme/2 model only shows the private and total vehicle volume between which there thus appears to be a discrepancy.)

Unfortunately, it is not possible to directly model mode changes, i.e. car to public transport transfers, within the assignment process. The usual method of dealing with this being a combination of variable demand auto assignment and a separate public transport assignment. This being the case, although variable demand modelling has its place in the process for determining the expected demand for public transport, unless there is a large segment of the demand for which the mode choice is easily swayed, this step belongs at the end of the basic design process.

From this multi-class assignment, the travel time on every link is copied to a link user-attribute, say UL1. The current scenario is copied to a new scenario and some changes made to the network model as discussed in the next section.

It could be argued that the multi-class assignment is unnecessary and that a free assignment of the public transport trips using the link travel times from a normal auto assignment would be adequate. The Ministry of Transport in Israel used this approach to investigate bus route alternatives (Elgar & Kfir 1992.) It should be remembered however, that once even a few hundred commuters an hour are using a road based public transport link, there can be significant impacts on the overall traffic distribution which affect both private and public transport traffic. This is of particular relevance where public transport demand is relatively high, as it is in South Africa. It is also a factor when corridor development is being considered, especially when alternative mode choices exist for public transport users.

4.5 REGULAR AND EXPRESS DEMAND

Keeping in mind the distinction between the operating period and the design-hour demand, if there is adequate demand between origin-destination pairs, the planner may be able to isolate potential express routes using the public transport demand matrix. First the planner must decide on some level of origin-destination demand at which to examine the possibilities of express routes. There is often a large part of the demand matrix in which the origin-destination demand is quite low. However, there may well be cases where a number of origins or destinations lie along a common route but do not individually fulfil the specification for an express route although in combination they would. There is also no reason why other passengers arriving at a stop on the express route, via another line or any other means, should not join the express route to the destination thus eliminating a regular line.

Quite clearly, any origin-destination pairs with sufficient demand to justify a service of their own qualify. However, lesser origin-destination demand values may form the basis for limited-stop express routes or be absorbed into the other express routes. The planner needs to experiment with this by setting different origin-destination demand values and then carrying out an assignment based on the resulting express matrix. A good basis for commencing the process is the viable demand of the smallest vehicle that will be considered for an express service. Thus, if the mini-bus taxi was to be considered, a minimum demand of 10 or 12 trips between origin-destination pairs may be required. Usually, express routes are operated by larger vehicles and over longer routes, rather than shorter ones. Thus, a minimum demand of 20 or 30 trips may be more sensible. Distance is also something of an issue here. An express route of four or five kilometres long is probably not justified, the time saving for the passengers not balancing the loss of service to others along the route for whom service frequency is now reduced.

The express matrix is created by filtering the public transport demand matrix to only show those origin-destination pairs with at least the specified minimum demand and at least some minimum distance apart on the network. This done, the reverse direction trips are added to the matrix and finally the express demand matrix, is subtracted from the original public transport demand matrix to provide the regular demand matrix. (See APPENDIX E for the step by step method of creating the two matrices.)

It is possible for an origin and destination pair to lie along a high capacity carrier, such as a railway line, in which case the provision of an express service may not be justified. This sort of occurrence will have to be dealt with on an individual basis. When such an event does occur, the relevant demand must be excluded from the express matrix and included in the general demand matrix unless some other motivating factor justifies special treatment of the case.

The planner is now able to carry out an assignment of the demand reflected in the express matrix. This assignment is later subjected to the route extraction process and may result in suitable express or limited stop routes. In the route extraction process, link demand not assigned to an express line is transferred to the regular link demand and so is considered in the design of the conventional routes. This transfer is justified on the basis that, by definition, the express demand will usually be adequate to form a route even if there is no other demand on the link. The transfer process means that the choice of distance and demand levels is not critical.

Although not vital to the process, this split of the demand matrix into regular and express demand enhances the route extraction results by satisfying the direct demand in a positive way. The removal of the express demand from the main demand also simplifies the regular route extraction process to some extent. The single class assignment is now run again with the regular demand matrix just derived.

4.6 SINGLE-CLASS ASSIGNMENT AND FOCUSING

The new scenario created from the multi-class assignment is now modified so that all links have a volume delay function reflecting the link travel times derived in the multi-class assignment. This is done by creating a link volume delay function (fd99 say) which is set to the value of the link travel time stored in link-user-attribute 1 (UL1). (For example: fd99=UL1.) This is based on the assumption that the focusing process will have little impact on the link travel times. This may be justified by noting that the number of vehicle trips involved in the focusing process is relatively small. This is because the objective is to eliminate very low demand routes, which results in a change of perhaps one or two passenger car units on the links involved. Most of these trips will transfer to busier routes where larger vehicles can be used and where often, the spare seat capacity will absorb the additional demand without any additional vehicles. Even when more vehicles are required, where several smaller routes join a larger one, a change of four vehicles here, and ten somewhere else is unlikely to have a significant impact on overall travel times. This is however checked at the end of the focusing process.

If there are express and non-express demand matrices then once these minor modifications are made, the current scenario can be duplicated. The following steps are then applied equally to both scenarios except where specifically indicated to the contrary.

4.6.1 The first single-class assignment

A single-class, generalised-cost, assignment is performed with the express and regular demand matrices being used respectively in the modified scenarios. If the demand is uniformly distributed across the entire operating period, then sub-matrices, (express and regular demand,) of the full operating period demand matrix should be used. If the demand is not uniformly distributed, then sub-matrices of the design-hour demand should be used. The generalised-cost remains as before. Only the public transport demand is assigned and this without a vehicle occupancy matrix; i.e. each trip maker is assigned as an individual. The result of this assignment is similar to the multi-class assignment, inasmuch as that the same fundamental link volumes pertain albeit that the vehicles are now split into trips and the private traffic is only represented by virtue of travel time. (This happens because the travel time is now unaffected by the demand volume and trip makers simply choose the shortest generalised-cost path.) This assignment still assumes that there is a "perfect" public transport system in which there is negligible waiting time or transfer penalty. An example of the single-class assignment graphic is shown in Figure 9-3 in Chapter 9, the case study.

4.6.2 Focusing

After the first single class-assignment, the model(s) will probably have many links with insufficient demand to justify any sort of public transport service. This low demand problem is minimised by focusing the trips onto busier routes wherever possible, achieved by iterative modification of the demand penalty component of the fixed-cost on the links. This focusing process is a balancing act. On the one hand, it is important to ensure that the public transport system operates viably across the different temporal demand patterns. On the other, it is equally important to avoid long, indirect routes that would cause users to switch to private transport. (The customers are obliged to take higher cost paths when there is insufficient demand on their first choice, or choices, of path.)

The focusing process is controlled in the Emme/2 model by using the mode and policy attribute definitions as a filter for applying the demand penalty. For example, pedestrian links joining two major public transport lines may exist. In the form in which the public transport-planning model is set up, these links are "auto" links although they do not carry vehicular traffic. Even allowing for walk time and penalty, public transport users may choose to transfer using the walk link. This transfer will not impact directly on the cost of providing public transport and so it does not matter how many people make use of the walk link. Pedestrian links should thus be excluded from the focusing process. The size of the focusing step may be different for the express scenarios given that the minimum link demand must equal or exceed the specified origin-destination demand and that the number of stops is to be limited. The focusing process is shown schematically in Figure 4-4.

The focusing process proceeds as follows:

- For each of the operational periods, the link indices are determined based on the link volumes for each operational period.
- The indices are imported into one scenario where they are used to calculate the composite indices as per Equation 4-9.
- The composite indices are used to calculate the demand penalties as per Equation 4-10.
- If there are no operating period factors involved, the demand penalties are used to determine the new fixed link costs which are then copied back to the scenarios for the different operational periods.
- If there are operating period factors involved, the demand penalties are copied to the scenarios for the different operating periods and used to calculate the fixed link costs. The fixed link costs are determined as:

Equation 4-11:

$$Fixed\ cost = \left(Link\ length * \frac{Fare}{Value\ of\ time} + Demand\ \ penalty + Policy\ \ factor \right)$$

- A new single class assignment is run for each operational period.

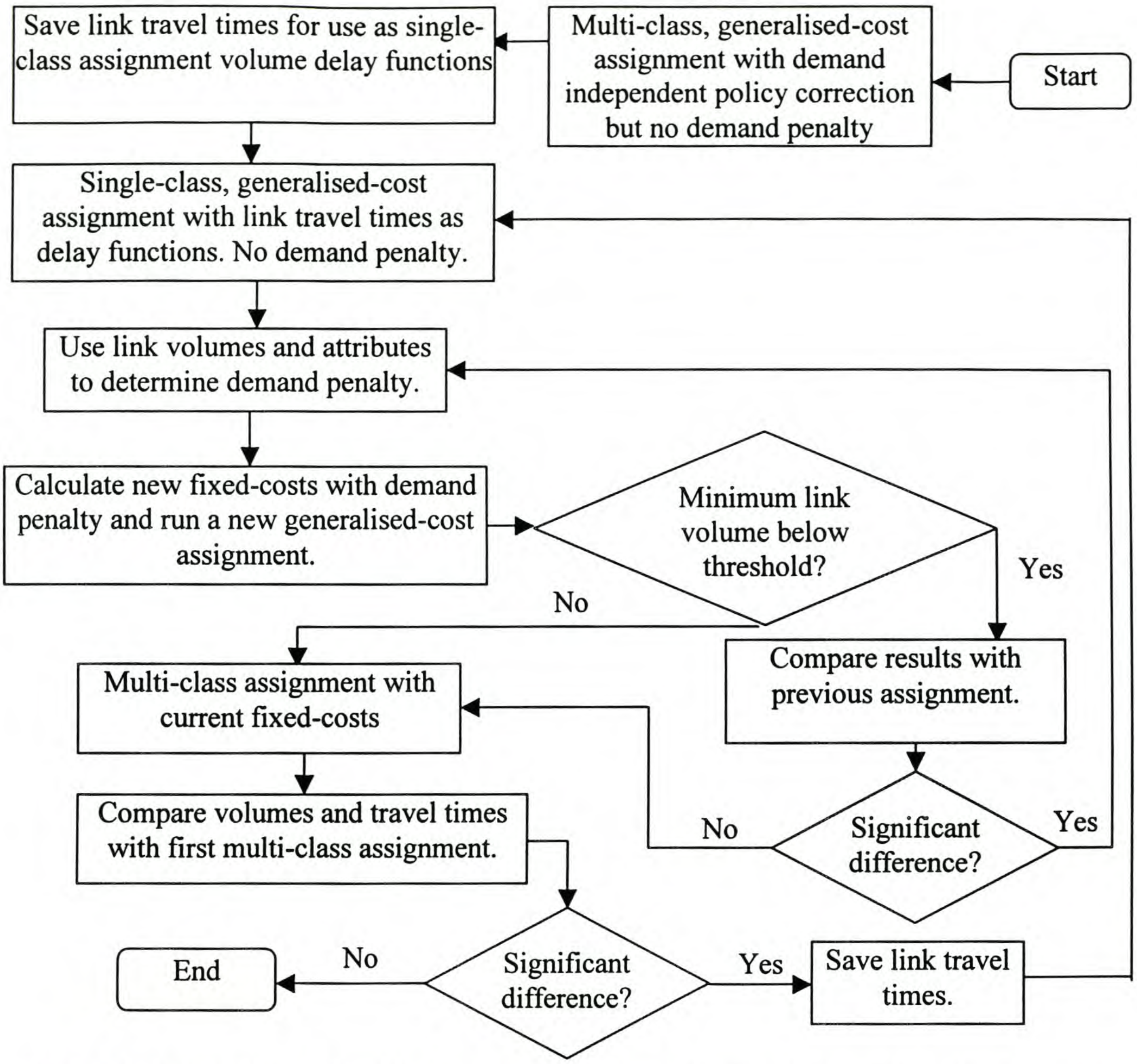

Figure 4-4: Flowchart of public transport system route development focusing process.

The focusing process is repeated until one of two conditions occurs in all the operating period scenarios.

- Most links have a demand exceeding that required to support the policy frequency, additional focusing will unduly constrain the service.
- There is no change in link volumes between successive iterations.

This step-wise focusing process, necessary to overcome the non-decreasing requirement for the volume delay functions, can be justified by noting that public transport is usually provided in discrete packets, not as a continuous entity. This being the case, there will equally be discrete jumps in the perceived performance of the system.

After each such assignment step, it will be found that many of the trips on low volume links will have chosen alternative routes. These alternatives are longer in travel time and distance terms, but result in a lower overall generalised trip cost; (within the modelling process.) In the first few iterations, there will tend to be a visible difference in the graphic assignment results, the degree of which will depend on the step size used in the calculation of the link index. The difference in link volumes between one iteration and the next is obtained using the Emme/2 module 6.13.

After a number of iterations of the regular demand scenarios, four in the case study, the change in link volumes between one assignment and the next will be quite small. (In the express scenarios, only one or two focusing steps are required.) This happens when the demand on most links exceeds the maximum demand specified in the link index calculation. In other words, when most links will support a frequency equal to the iteration step number or greater.

In the off-peak periods, the lower demand levels may result in excessive focusing, producing a system of routes not realistically satisfying customer needs. When this occurs, the planner should give thought to stopping the focusing process for the off-peak periods whilst continuing with the focusing of the peak periods. In this way, active off-peak links will be favoured for use in the later focusing steps of the busier operating periods. This is achieved by marking the sufficiently busy links for the off-peak operating periods and then not assigning a demand penalty to these links in the busier operating periods. This will result in more routes being developed, covering a wider range of travel options. It may be possible to separate these routes into commuter routes, operated only in peak periods, and regular routes, operated during all periods.

The result of the multi-period focusing process is that all trips, irrespective of the time of day, will tend to be focused onto the same links. The result is that the fixed infrastructure is utilised at all times although the exact routes may differ from period to period. The route extraction program is carried out for each period separately and will probably result in common routes for the morning and evening peaks with slightly different routes in the off-peak periods.

Once the focusing is complete, the fixed link costs obtained in the last single class assignment should be used to perform a new multi-class assignment similar to the one carried out at the beginning of the process. The link travel times of the first and last multi-class assignments should now be compared to ensure that the focusing process has not resulted in changes in the link travel times that will influence the transport system performance. If the travel times are considered a problem, they should be saved as the basis for a repetition of the focusing process. (The high travel time on the problem links will discourage public transport use on those links resulting in revised travel paths.)

Before repeating the focusing process, the link volumes and travel times of the final multi-class assignment should also be evaluated on their own merit. Although unlikely, it is possible that the public transport design generated by the focusing process could give rise to congestion problems which will be shown in the model. If there are such problems, the planner will have to evaluate them on merit and perhaps alter the policy factors used in the planning process. The entire exercise will then have to be repeated until satisfactory results are achieved. Alternatively, the problem may justify planning actions outside the sphere of the public transport system. For example, a traffic circle may be required at an intersection.

4.7 OUTPUT RESULTS

4.7.1 Link data

Once the focusing process has been completed, Emme/2 contains a databank in which the link travel time and public transport demand are available for every link in the network. This link data is separated into express and regular demand for each operating period. This information can be used, in Emme/2, to create useful graphic representations of the potential public transport routes. There is however, no mechanism within the Emme/2 package for converting the graphic or the databank into a set of route definitions. This must be carried out in a separate process. In order to do so, the base-network data and the final single-class assignment results must be output using the Emme/2 punch command. Suitable names must be given to the punched files so that they can be recognised later. All the output data is read into the decision support system database. The base-network data can be modified to include such information as street names and the types of facilities existing at nodes. The assignment results are stored separately from the base-network data, so that they can be replaced with revised data without losing enhanced base network data.

4.7.2 Express route node sequences

Under certain circumstances, it is possible to extract the node sequence for a route or potential route directly from the Emme/2 model. This applies in particular to the Express routes where the origin and destination of the routes are directly associated with the origin-destination demand.

Using the assignment graphic of the final express scenario, the start and end nodes of potential routes can be identified. This information can be used in conjunction with module 6.15, option 3.

```
6.15  PLOT SHORTEST PATHS ON AUTO NETWORK
Select: 1= shortest distance paths
        2 = shortest time paths
        3 = minimum generalized cost paths
        4 = change module parameters
        5 = end
```

The module parameters must be set as follows:

```
Allow paths from/to all nodes?y
Generate transcript of interactive queries into the batch output file?y
```

This done, when the shortest path graphic is shown, typing c↵ and then b will send the path between the selected nodes to the output file:

```
c EMME/2 Module:  6.15(v9.03)  Date: 00-12-07 17:38   User: E644/USCIV.....wdr
c Project:        EMME/2 STANDARD DEMONSTRATION AND TEST DATA BANK
c Scenario 10000: Express - Demand >50.
c
c Active auto mode:        t AllTransit
c Shortest paths based on: gen.cost =    1*ul3  +     1*timau
c
c  from    to    cost        path:
a   181   981    30.         705   181   180   179   178   177   176   175   174
                             173   172   171   170   169   168   167   166
                             165   1055  1059  1051  1050  1047  1046  1045
                             1044  1043  1042  1025  1021  1005  981
```

This can then be compared with the results of the route extraction process as shall be seen.

4.7.3 Performance measures

During the route extraction process, one of the values calculated is the number of passenger-kilometres travelled on each line as well as the total passenger-kilometres on the network. The ratio of the minimum possible, (assuming all demand is satisfied,) to the actual passenger-kilometres is an important measure of performance. The minimum possible passenger-kilometres for the network and for each origin-destination pair can be determined in Emme/2. To do this, an assignment is performed where the demand matrix is a single element matrix with a value of one. For a direct comparison with the route extraction program results, all centroidal links must be assigned a zero travel time. This is because of the exclusion of the centroidal links from the route extraction process. The other link volume delay functions can remain unchanged. The "travel time" resulting from the assignment is the shortest distance between every origin destination pair, excluding the centroidal link distance. Saving this "travel time" matrix and then multiplying it by the public transport demand matrix, one obtains a matrix of the minimum passenger kilometres possible.

4.7.4 Graphic enhancement

Whilst still in Emme/2, it is possible to greatly enhance the visual representation of the data. Since centroids are actually hypothetical points for most purposes, we eliminate them from the graphic by electing to show only links for which neither node is a centroid. This is achieved very simply using the Emme/2 link and node selection keywords ci and cj. (Emme/2 User Manual pg. 3-36.) The result is a "real" image of the potential public transport network. (How to do this is shown in APPENDIX F.)

Another enhancement lies in the determination of the demand at which a change over from one road mode to another would be economically sensible. This is an element of the route extraction process as well and is discussed in detail there. In the mean time, as an example: For a demand of under 200 passengers per hour, mini-bus taxi may be the best option. Between 200 and 1000 trips per hour, a standard bus service may be ideal. Over 1000 trips per hour, a dedicated right of way may be worthwhile. By using the link volumes and the allowable modes to identify links, colour coding can be applied to show each category of public transport. In this way, feeder, regular and high capacity road based services can be shown as can rail and other non-road mode services, each in a different colour and line format. This is useful for checking the focusing and route extraction process results and for presentation purposes. Example results of this process are shown in Figure 9-4 in Chapter 9, the case study.

4.8 FEEDBACK AND ANALYSIS — TESTING THE RESULTS

The process of converting the link volumes into public transport routes and the subsequent assignment of resources to these potential routes is outside the scope of the Emme/2 network model, and all other such network models to the best knowledge of the author. These processes, discussed in the following chapters, are thus performed externally to the Emme/2 model. Once the routes are fully defined however, Emme/2 again provides useful tools for further analysing the performance of the public transport system using the "Transit Assignment" option.

The Emme/2 User Manual discusses the transit assignment process in detail and the reader is thus referred to that reference. Worth noting here is that there are three primary objectives for running the transit assignment:

- To test the design capacities and frequencies, allowing for the explicit incorporation of waiting and transfer penalties into the route selection equation in a more conventional manner.
- To compare alternative public transport system designs in terms of user and operator perceptions of performance. Thus, the proposed new system may be compared with the existing system or alternative proposals based on different policy decisions.
- To provide additional boarding and alighting volume data for the further planning of access points and interchange facilities.

The testing process is discussed in more detail in Chapter 9, the case study.

4.9 AREAS FOR FURTHER DEVELOPMENT AND IMPROVEMENT

The ideal network model would include two considerations that can be modelled in Emme/2 but that are considered too complex to include in the public transport design process at this stage of development. These are:

- Variable demand modelling, mentioned previously but not implemented in the study, where the demand for various modes of transport changes according to the generalised-cost of making the trip. Examples can be found in the Emme/2 User's Manual (INRO 1999) and the Emme/2 course material: Advanced Topics on Auto Assignment – Variable Demand Assignment. (INRO 1999)
- Transfers from car to public transport at park and ride or drop and ride points. An example can be found in the Emme/2 course material: Advanced Topics: Transit Assignment - Park-and-Ride and Matrix Convolutions. (INRO 1999)

It is recognised that the degree of accuracy in the routing of the public transport vehicles resulting from the network model is dependent on the number of zones employed and the completeness of the network model. It is unusual to model larger cities with the degree of accuracy required to fine-tune the routes of road based public transport vehicles. Such local routing would thus have to be performed separately or the network model upgraded to include all possible routes and as many zones as necessary to realistically describe the access requirements of public transport users. Where a maximum walking distance is specified, the centroidal links should not exceed that length. In any event, the Emme/2 results provide a fair representation of how the public transport routes should be structured without any further processing. The process can however be taken considerably further.

4.10 REFERENCES

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5 ROUTE DEVELOPMENT

5.1 INTRODUCTION

The network model described in the previous chapter provided a method of focusing the public transport demand so that the level of demand on active links was sufficient to operate a public transport service. Whilst the standard network model is able to perform the necessary trip assignments and provide a graphic representation of the assignment results, it is not able to convert the results into public transport routes.

This chapter describes an empirical process that converts the network model output into potential public transport routes, which satisfy the travel demand whilst seeking to maximise vehicle utilisation. In APPENDIX K, a brief description is given of how Dijkstra's shortest path algorithm can be used to carry out the same process with some minor differences. Using Dijkstra's algorithm offers both advantages and disadvantages but is worth further evaluation in the future.

The route extraction process essentially operates by repeatedly extracting the current "maximum demand path," determining the line capacity and updating the network demand until no outstanding demand remains. The process must be seen in its context as part of decision support system – not as a push-button solution to the route design problem. Used independently of the focusing process, meaningless results may be obtained. In a strongly focused network, typical of urban areas, the results tend to need almost no modification. However, the route extraction results are intended as a basis for more detailed design work. This is especially the case in a CBD type environment with little directionality of travel apparent in the link volumes.

That said, even in the CBD environment the extraction process can produce results upon which it is difficult to improve by manual methods, as demonstrated in a simple example later. Results that are more comprehensive are presented in the case study. In the worst case, the results provide a good basis for the manual fine-tuning of the lines.

5.2 PREPARING THE ROUTE EXTRACTION INPUT DATA

The route extraction process is carried out within the public transport decision support system database (DSS.) The database and code are on the accompanying compact disc, which is briefly discussed in APPENDIX A. Aside from the program code for performing the extraction and other functions, the database contains a variety of network and system data, some of which duplicates that in the network model databank. The data as obtained from Emme/2, (INRO 1999,) is not immediately suitable for the extraction process and some modifications are required.

5.2.1 Centroid links

As noted in the previous chapter, centroids usually represent hypothetical zone centres in which all zone trips originate or terminate. Thus, the Emme/2 definition of centroids is such that trips may not pass through them, nor may transit lines start or end at centroids. In its auto-assignment process however, Emme/2 does model trips as physically starting or ending at centroids, which may have several entering and leaving links. This gives rise to link volumes that are perceived by the route extraction process as trips passing through the centroid. The result is that using this data, the extraction program will define public transport routes on hypothetical links and passing through or ending at centroid nodes. These routes would not necessarily be feasible. Even if the centroid links were "real" and the routes thus feasible, the resulting routes could not be modelled using the Emme/2 transit assignment option. The option of carrying out a transit assignment to test the new route system is thus lost.

It is possible to exclude the centroid links from the Emme/2 output but this restricts the flexibility of the data. The database is able to create Emme/2 batch input files and thus network modifications can be made in the database and used to construct a revised or new Emme/2 model providing that the centroid data is available in the database.

The centroid problem in the route extraction process is thus dealt with by filtering all centroid links out of the route extraction process. This is done automatically within the database, by comparing each link in the Emme/2 assignment result table with the base link data and using only non-centroidal links in the route extraction process.

5.2.2 One-way links

Road-based transport networks usually include some one-way streets and dual carriageways. In the latter, the two carriageways form part of the same conceptual road but are physically separate to the extent of being defined by different end nodes, equating to one-way streets. The result in the modelling process is that there are links in one direction but not in the other between node pairs.

Since the route extraction process assumes bi-directional links, the return paths for one-way links must be identified, when they exist. When the route extraction program does not find a normal return link, it then uses alternative reverse-link node numbers instead. These reverse-link node numbers are link attributes in the DSS database. (The Emme/2 network model node labels are unsuitable for this purpose.) The values are automatically entered as the J-I node numbers of the I-J link where the link is two-way. The reverse-link node numbers for one-way links must be entered manually but the DSS provides a mechanism to display the details of all one-way links, which can then be modified. This is a tedious process unless data is already available as the only way to find the reverse link is to use the Emme/2 graphic. Some enhancement is possible by altering a user link attribute in the database reflecting one-way links and then amending the Emme/2 databank accordingly, using colour to highlight the links. A macro "Setul1" is provided in the DSS to set the colour code in the database. The results can then be exported to Emme/2. The graphic for the Winnipeg case study model is shown in Figure 9-9 in Chapter 9.

The model currently assumes that for every link, there is only one return link. This is not always true, as there may be a one-to-many relationship between the forward and reverse directions. i.e. There may be two or more forward links for one reverse link or vice versa. (The ability to deal with this is not implemented in the demonstration version of the program.) Thus, the DSS database code will require modifications before implementation in a real planning exercise or dummy links must be created in the network model to create a one-to-one relationship between forward and reverse one-way links.

Street names are also link attributes in the DSS database. If the Emme/2 model was constructed from data in a GIS, (graphic information system,) then much of this data may be available already failing which it will have to be manually entered if wanted. The street names are useful in the line descriptions but can also be valuable in the one-way link modifications. Links can be selected by street name and thus in an ordered group and the related streets can be called up simultaneously, greatly facilitating the necessary modifications.

A remaining aid to the process is that if the return links are marked in the DSS after the network modelling is complete, the link volumes can also be displayed. This means that the forward and reverse links can be matched based on the demand volume. This is useful where there are alternative matches, as may occur where a series of parallel one-way streets go in alternate directions. The assignment process may have focused the bulk of the trips onto only a few of those links and these should then be used as the matching pairs.

When the very unusual case exists that the path really is one way only, the route must form a loop. There will usually be very limited options for route choice in this situation and the route extraction process will go no further wrong than perhaps not closing the loop, which must be done manually if necessary. If no reverse link is found, the process simply does not add the additional length, time, and passenger-kilometres, which would be associated with such a return path.

5.2.3 Mode definitions

Although the network model is modeless, the route extraction process is not. Given that there may be several sub-modes specified, it is necessary to create mode groups such as road and rail to which the sub-modes are then allocated. Each link is then categorised in terms of its mode group using its mode definition in the DSS database. Although more specific restrictions, such as minimum or maximum vehicle size on a set of links, could be implemented here, such restrictions are better implemented in the vehicle allocation process described in the next chapter.

5.3 FACTORS IN ROUTE IDENTIFICATION.

The route extraction process is based on the premise that a potential public transport route is one on which the demand for travel is such that at least one of the available public transport modes is able to operate economically. This implies that the route should:

a) Be sufficiently direct between origin-destination pairs, to minimise travel time on the path for which there is the demand. (No-one using the route should be forced to take an unduly indirect route for his or her trip.)

b) Be of sufficient length to preclude walking as a practical option. (If the customer can make the trip more quickly on foot than using public transport, (s)he has no motivation to pay for the service.)

c) Have sufficient demand to enable the economic provision of a public transport service.

The directness of travel is established in the network model assignment process where passengers choose the path of lowest generalised-cost, which by virtue of link travel times, includes an allowance for network congestion. The assignment process does not explicitly allow for waiting time and transfer penalties. The focusing process however, which is based on maximum viable service frequency, results in an implicit inclusion of the effects of waiting time and transfer. Frequency because, below the target minimum, the lower the viable frequency, the higher the waiting time, reflected as an increased demand penalty. Transfer because the higher the demand along a route, the more likely it is that there will be an unbroken service, eliminating transfers, thus lowering the cost of the trip.

In the focusing process applied in the network model, the objective is to discourage the use of network links with inadequate demand, starting with the lowest demand volumes. When extracting routes however, busier routes are sought first. The higher the demand, the earlier the link is selected as part of a route. This means that the larger the demand between two places, the less likely that a transfer will be necessary in travelling between them. Since minor routes often form part of larger routes, this means that some of the low demand routes will be "absorbed" into the high demand routes, favouring transfers for more obscure origin-destination pairs.

The other factors, demand and route length, have to be established along with a few other criteria before the extraction process is carried out. This involves the creation of route categories.

5.4 ROUTE CATEGORIES

Technically, the route extraction process is the same for all modes. There is however very little scope for changing the routing and terminal points of non-road modes. With rail for example, it is not possible to run one train up to some arbitrary point and then run two trains from that point. At the same time, the Emme/2 network-modelling process will either have defined a viable non-road mode or excluded it completely during the focusing process. The process description thus focuses on the road mode. The road-mode route extraction process may of course produce results implying that a dedicated or exclusive right-of-way service should be considered in place of a conventional road service or that a non-road mode service should be extended.

Whilst the non-road mode routes are limited in terms of their design, the road-mode is not constrained in this way. Transfer points can, in theory at least, be placed anywhere on the road network. The maximum possible number of vehicles per hour is usually relatively high and the length of the route can range from a few hundred metres to hundreds of kilometres. There are many vehicle types and capacities available and these can normally operate on the same travel-way, except in the case of special exclusive right-of-way facilities. The choices are thus many.

Not all choices are reasonable though, and the primary objective is a prescribed level of customer service at the lowest possible cost.

Given this objective, some ways in which the public transport network can be configured will be better than others are. These configurations depend on the available fleet and the demand patterns. Public transport design is usually governed by the peak-period demand patterns and it is to satisfy this demand that large public transport vehicles are required. Whilst the use of the smallest possible vehicles at all times will most closely approximate private car travel in terms of area coverage and waiting times they will often create congestion problems of their own, especially at bus stops. It is also commonly perceived that over a certain level of demand, larger vehicles are more economical per passenger-kilometre in both monetary and environmental respects. Interestingly, del Mistro and Aucamp (2000) established that in South Africa, the newly introduced 18 seat mini-bus taxis are a very competitive form of public transport for one-way peak period volumes of up to 20 000 passengers on distances up to about 20km. This tends to contradict the traditional perception and justifies the vehicle allocation process described in the next chapter.

The large vehicles, suited to peak-period operation, are often very expensive to purchase and are poorly utilised during the off-peak periods. Even during the peak period, large vehicles are often under-utilised by virtue of operating on route segments better suited to smaller vehicles. Smaller vehicles usually have lower total, (not per passenger-kilometre,) fixed and operating costs and are more suited to the off-peak demand. Thus, the correct balance between large and small vehicles can reduce overall costs at a given level of service, especially during the off-peak. (It is the author's contention that in South Africa, many potential public transport users choose private transport because of poor off-peak services, which fail to provide for off-peak commuting.) Routes thus need to be designed so that the larger vehicles are turned around at the appropriate point, thus limiting the number required and thus the overall cost of the system. This naturally has the drawback of requiring additional transfers, but with the advantages of better coverage and / or less costly services.

Seeking this balance with the route extraction program requires that the planners categorise the road fleet, grouping vehicles into capacity categories, and provide process control values identifying these categories as follows:

- Minimum route length for each category.
- Target minimum demand for each category.
- Minimum remaining demand.
- Minimum utilisation factor for consideration of a route extension.
- Express or non-express. (A true or false condition.)

How the categories are developed is described in the following sections.

5.4.1 Route length

Unlike the non-road mode case, the road-mode routes can be any length although, practically speaking, the minimum route length for road modes is the acceptable walking distance. (A bus route 300m long is usually pointless.) The minimum route length is really a function of the demand between two points. Thus, a 500m route that satisfies a demand and keeps one or more vehicles profitably utilised is justified.

In practice, the route extraction program has no "knowledge" of origins and destinations and the associated demand and is thus unable to distinguish functional short routes from link sequences that should rather be part of longer routes. Consequently, it is preferable to specify some minimum route length at least as long as the maximum walking distance acceptable. There are also practical considerations, inasmuch as that, for example, a large bus cannot simply do a U-turn at each end of a street. Experimentation indicates that a minimum one-way route length of at least 1km and preferably longer be specified for all except the smallest vehicle category. This prevents arbitrary links being selected as very short, and usually physically impractical, routes by a high capacity vehicle category. (The links from which these short routes arise are usually connected to a number of feeder links.) The smallest category should equally not specify too long a length for otherwise viable and necessary lines may be missed, being too short.

The minimum length specification has another application as well. When high demand is present along a path, exclusive bus lanes, (EBL — physically separated lanes,) as opposed to regular bus lanes, (RBL — ordinary lanes reserved for high occupancy vehicles,) may be justified. This often requires major construction and is usually very expensive. Since short sections of such right-of-way rarely produce any benefit, being constrained by the entrance to and exit from the right of way, the implementation of such a right-of-way may be expected to occur only when the path is greater than some minimum length. For example, three links feeding into a one-kilometre link may produce a very high volume on that link. If at the end of the link however, the demand divides again, although an RBL may be justified, an EBL is almost certainly not. The planner may thus wish to separate out potential routes with sufficient demand and length to justify evaluation of an EBL. Some guidance with respect to the design of such facilities is provided by Vuchic (1981, chpt. 4.)

There are also specific, vehicle-based considerations in determining route length. The route extraction program however, does not attempt to assign vehicles to routes, only to design routes for which the demand is suited to certain classes of vehicle. The resource allocation process provides for vehicle rather than category based rules to optimise the deployment of specialist vehicles.

5.4.2 Target minimum demand

In the context in which this work is presented there are several vehicle categories. The most common vehicle types are the minibus-taxis with a capacity of about 14 passengers and the conventional buses with a capacity of around 60 passengers. There is also a government program to replace the 14 seater with 18 and 28 seaters, the latter of which will have a total capacity of around 35 passengers. There are vehicles, smaller than the 14-seat mini-bus taxi, operating commercially and there are many other capacities available. Articulated buses carrying 125 passengers, or more, are being in use in some South African cities and many other cities around the world.

This variety of vehicles is important for two reasons. Firstly, there are cost implications associated with using different vehicle types. Secondly, there is considerable benefit to be gained from matching the frequency of connecting routes so that some co-ordination of services can be achieved. Vuchic et al (1981) propose the "Timed Transfer" concept in which routes are designed to have a "pulsed," common layover period at focus points where interchange can take place. This requires that a common service frequency is maintained on routes meeting at the focal points. Since many routes may be expected to encounter at least two focal points, this requires a system wide frequency to function effectively.

To achieve a common minimum service frequency across the network given the various route demand levels, either the route travel times will have to be matched or different vehicles will be required on different routes to avoid gross under-utilisation on some routes. Which vehicles are chosen depends on the vehicle operating costs and capacities and gives rise to the target minimum demand value. A simple example demonstrates the point:

Assume that we only have two vehicle types available; A 14-passenger taxi and a 60-passenger bus. The total cost per kilometre of the taxi is R 2-69 and of the bus is R 4-76. Evaluating the total cost for the two types given the minimum possible frequency and the policy frequency results in the costs as shown in Table 5-1.

Bus	Total Cost / km		R4.76					
Taxi	Total Cost / km		R2.69					
Required capacity	Minimum vehicle trips				Policy frequency = 4 Veh/hr			
	Taxis	Buses	TaxiCost	BusCost	Taxis	Buses	TaxiCost	BusCost
14	1	1	**R2.69**	R4.76	4	4	R10.76	R19.04
28	2	1	R5.38	**R4.76**	4	4	R10.76	R19.04
42	3	1	R8.07	R4.76	4	4	R10.76	R19.04
56	4	1	R10.76	R4.76	4	4	R10.76	R19.04
70	5	2	R13.45	R9.52	5	4	R13.45	R19.04
84	6	2	R16.14	R9.52	6	4	R16.14	R19.04
98	7	2	R18.83	R9.52	7	4	**R18.83**	R19.04
112	8	2	R21.52	R9.52	8	4	R21.52	**R19.04**
126	9	3	R24.21	R14.28	9	4	R24.21	R19.04
140	10	3	R26.9	R14.28	10	4	R26.9	R19.04

Table 5-1: The cost implication of policy-frequency on vehicle choice.

In this example, given the situation where the service frequency is just adequate to carry the demand, the bus is cheaper as soon as the peak segment demand exceeds 14 passengers. However, when it is policy to attempt to provide at least four vehicle trips per hour, the picture changes. In this case, the taxi is cheaper until more than seven taxi trips are required to meet the peak segment demand. The demand at which to change the vehicle type is thus 98 passengers. This would be the target minimum demand value for a bus oriented route system. It would also be the value used in the enhancement of the Emme/2 assignment result graphic discussed at the end of the last chapter. (Figure 9-4 in Chapter 9, the case study, provides an example of this.) Where there are other vehicle types, or the estimated total vehicle cost per kilometre is different, other values will be applicable. Within the extraction process, this target minimum demand is used as a filter value and only links with demand greater than this value in at least one direction are included in the route selection process for the category. In South Africa, probably at least four categories should be created, based on vehicle capacities of the following order:

< 20; 20 to < 45; 45 to < 70; ≥ 70.

In order that all links be considered for inclusion in a route, the target minimum of the smallest category should be set to one or the absolute minimum acceptable demand value, usually the viable demand for the smallest vehicle. Setting the value to one may result in some poorly utilised lines but these can be modified manually later. This avoids totally ignoring some potential customers and the possibility of breaking a line across a low demand link. When some demand is unaccounted for after the first phase of the extraction process, an effort is made to absorb the trips into existing lines. The details of this process are discussed later.

There is another use for these minimum demand values as well. As mentioned in the discussion on minimum route lengths, exclusive bus lanes may be worthwhile, usually when very high demand is present. A category may thus be created which has nothing to do with frequency but rather to do with exclusive bus lanes. The minimum viable demand and length of such a lane structure may be specified as a category.

Regular bus lanes, as opposed to exclusive, right-of-way, are not dealt with in this way but by examining the travel time on links with high demand levels once the rest of the route construction process is complete. In the event that either exclusive or regular bus lanes are considered, the network model should be modified to reflect this change. The entire network modelling process should then be repeated, as it is quite likely that there will be a change in the demand pattern further favouring the bus lane.

In large and well-focused networks, this use of demand categories works effectively to create trunk and feeder routes in which the frequency balancing also tends to be resolved by the meeting of two or three feeders at the interchange. Low capacity feeders will tend to have a frequency of the same order as the high-capacity trunk-route. Unrealistic use of these categories can lead to poor line design, especially with very small or very densely travelled networks and thus, the planner should experiment with the process parameters during the design process.

5.4.3 Minimum remaining demand

Given the minimum target demand level, assume that a route is specified on which all except one or two links actually have this demand whilst the odd ones have a higher demand. If we were to set the minimum target demand as the route capacity, the extra demand would be left on these few links. Ignoring other factors, the question arises as to whether these outstanding trips will justify a new route of any category. Depending on the general design philosophy, the answer may change from one category to another. For example, we probably do not want low capacity vehicles on a high capacity route but will accept medium capacity vehicles. Thus, a high capacity route should be specified so that if outstanding trips are left, the outstanding demand will justify a medium capacity route. If there is not sufficient outstanding demand, the high capacity route must carry all the trips, meaning an increase in its specified capacity. For each category, the minimum number of trips that may be left on the links after the route is declared is the minimum remaining demand. This essentially forces feeder routes for low capacity links entering and leaving a high capacity route but will allow parallel medium capacity routes.

For the smallest category, this definition does not hold. Here, the minimum remaining demand specifies the minimum viable capacity for the development of a new route in this category. In other words, the remaining demand left after declaring a route in this category must be sufficient to justify a new viable route in the category. Normally in this case, the minimum remaining demand is set at the policy frequency times the viable demand for the smallest vehicle.

5.4.4 Minimum utilisation factor

The sustainability of a public transport route is reliant on the income at least meeting the expenses. In the long run, this ideally implies that the fare revenue should equal the costs so that subsidisation is not required. Since the fare should be less than the cost of using private transport, the vehicle utilisation must be kept as high as possible. Although not a guarantee of best economic efficiency, smaller vehicles sometimes being more costly than bigger ones, a useful measure of performance is the ratio of passenger-kilometres to space-kilometres. (As demonstrated in Table 5-1, 26% utilisation of a 14-seat minibus taxi may be more expensive than 12.5% utilisation of a 60-space bus.)

In the route extraction process, this utilisation ratio is used to determine whether or not a route can be extended, or its capacity increased, to accommodate outstanding demand. For example, a public transport route ends at point A but there are a few passengers on the line who wish to travel further, too few for inclusion in the main extraction process. Should the line be extended for these few passengers or not? If the overall line utilisation is high, increasing the route by the extra link or links may lower the utilisation rate but it may nevertheless still be acceptable, thus satisfying more customers and providing additional potential for new customers. How far can the line be extended? If the utilisation rate is low, to extend the line for a few passengers will simply make the matter worse. Thus, the planner should specify some minimum utilisation factor, below which a route should not go if it is modified. This ratio does not affect the initial route extraction process, which seeks to maximise the vehicle utilisation ratio for the entire system, but only the extension of routes to accommodate a few remaining trips.

In the case that a route cannot be extended in this way, the route could be manually modified to reflect every nth vehicle trip going the extra distance to accommodate the customers but on a lower frequency service.

5.4.5 The express route category

The parameters for the express routes are different from those for the regular routes as they are directly linked to the values specified in preparing the express demand matrix discussed in the previous chapter. This is dealt with in the route extraction program by marking the categories according to whether they are express or regular categories. Usually, only one express category should be specified. The minimum demand should be that used to separate the potential express demand from the regular demand; i.e. the minimum origin-destination demand specified to extract the express demand matrix. This is necessary because the express lines will almost certainly start or end at nodes where there is not enough demand to justify a dedicated service although the express service is justified by passengers joining at a fewintermediate stops. The minimum remainder can be set at the minimum viable demand, which will be the demand considered necessary to operate an express service and will be equal to or higher than the minimum target demand.

5.5 THE ALGORITHM

Once these categories have been established, the route extraction process is carried out as follows, (automatically within the DSS database,) for each of the operating periods:

THE ROUTE EXTRACTION ALGORITHM.

1. Starting with the express data:
2. Select the first mode group to be processed. (Road, rail, other.)
3. Filter the Emme/2 assignment results to reflect only the selected mode group.
4. Filter the mode results to show only the links having a one or two-way demand greater than or equal to the largest "target minimum demand" value and not marked as unsatisfactory. (See Note 1)
5. Find the network link with the highest outstanding one or two-way demand. (See Note 2)

6. Find the downstream connecting link with the highest one or two-way demand. (See Note 3.)
7. Follow the trail until no more links remain, each time testing the link for potential entering and leaving branches.
8. Go back to the first link and track the links upstream as per steps 6 and 7.
9. Test to see if the route is long enough. If it is, go to 11. If it is not, go to 10.
10. Test to see if there are branches. If there are, test the branches as described in the section 5.5.1, "Minimum route length," and then go to 11 if an acceptable branch is found or mark the first link and go to 4.
11. Determine the route capacity. (This will be described fully in a later section.)
12. Determine the proportion of the outstanding trips, in the forward direction, represented by the proposed capacity.
13. Subtract the lesser of the capacity and the outstanding trips from the outstanding demand for the forward direction on all the links in the set. (See Note 4.) Record the actual trips and the passenger-kilometres assigned to the route on this segment.
14. Subtract the proportion of the trips, calculated in 12 from the reverse link if it exists. (A route is usually assumed bi-directional.) Record the actual trips and the passenger-kilometres assigned to the route on this segment.
15. Save the route-set. The route set contains the node sequence, the route capacity, the passenger-kilometres, and other data. The process also includes updating the number of times each link is used.
16. Reapply the filter of step 4 to the links. If there are no links in the resulting set, clear the "unsatisfactory" markers and move to the next vehicle category. Go to 4.
17. Repeat the process again with the revised link set.
18. Repeat until no links with outstanding demand can be used to create a new route. If using express data, go to 19, if dealing with regular data go to step 21.
19. Add the outstanding demand on the express network to the regular network demand.
20. Change to the regular data and return to step 4.
21. Test the network data for outstanding trips and where possible assign these to defined routes, which may be modified if necessary.
22. When no more routes can be defined or demand catered for in the mode, select the next mode and go back to step 3 until there are no more modes.
23. The process is complete.

Notes:

1. There are two possibilities in respect of link selection. Either the one-way or the two-way volume can be used to make the selection. Using the two-way volume as the selection criterion can marginally improve vehicle utilisation but does not always satisfy the immediate customer demand when there are strongly directed demand patterns. Thus, in the DSS the one-way volume is used as the selection criterion.
2. The route extraction process is to some extent, dependent on the sort order of the links in the database. Where two or more links could equally be the first choice for a route and the routes arising from these links share common sections somewhere on the network, a different route set could arise out of the choice of the first link with which to start a new route. A similar problem arises when two links with the same demand volume are the choices at a branch. This sort order problem can be eliminated using a modified version of Dijkstra's shortest path algorithm discussed in APPENDIX K. This method does however introduce some other problems of its own.
3. As the route definition process proceeds, the extraction program marks each selected link, its reverse, and the links leaving or entering it, except for the links comprising the next path option. Marked links are not available for selection again until a new route is started. This prevents routes backtracking or crossing over themselves.
4. It is assumed that in the forward direction, the maximum number of users makes use of the service. The reason for this is discussed in some detail in section 5.5.2, Determining the route capacity."

This approach to route development is based on the fact that the link volumes reflect, to a greater or lesser extent, the origin-destination demand patterns, particularly in the express route analysis. By seeking the links with the highest volumes, links joining areas of high production and attraction will be provided with linking lines first, thus minimising the number of transfers. It is of course possible that there is a crossover, so that a high production area is linked to the wrong high attraction. Given however, that trip matrices are usually generated using gravity type models, proportionality will tend to exist in the modelled link volumes; i.e. the demand on a series of links joining a production and attraction will tend to be proportional to the magnitude of the production and attraction. As volumes decrease, the chance of a direct route is reduced, as would be expected for two reasons:

1. In order to avoid small numbers of trips being left on some links, the capacity of a route often absorbs the trips, from an origin or to a destination, entering or leaving the network along the

route, thus eliminating the origin or destination from further consideration in the extraction process. This is especially the case on trunk route sections.

2. Where the origins and destinations are not absorbed into larger routes, except in isolated cases, the connection between any particular origin-destination pair will be tenuous, viewed from the perspective of the link volumes.

5.5.1 Minimum route length

As already mentioned, each route category has a minimum length specification. As a link sequence is built up in the route extraction process, the route length is determined. Once the ends of the sequence have been reached, the route length is tested against the specification. If it passes the test, then the capacity determination can proceed. The route length does not always pass the test however. If there are no feasible branches to the route, then at this point, the first selected link in the current sequence is marked as unsatisfactory and the entire search process repeated. This might of course entail having to sequentially mark all the links in the current sequence.

If there is a possible branch however, then it is necessary to determine the position of the first link (the maximum demand outstanding on the network,) in the current sequence with respect to the branch or branches and the type of branch, entering or leaving. If the first link is above the first entering link, or below the last leaving link, the first link is marked as unsatisfactory and a new route is sought. If however, the first link lies below an entering branch or above an exiting branch, then:

- If there is only an entering link, we block the links above the branch and search the path along the entering link.
- If there is only an exiting link, we block the links below the branch and search the path along the exiting link.
- If there are both entering and leaving links, we arbitrarily block the links below the last exiting branch and search the path along the exiting link. Since we do not keep a record of the alternatives, this must be modified in a more detailed model to allow the longest upstream and downstream branches to be connected.

Each time the new route fails the route length test, a link is marked as unsatisfactory, thus blocking a particular path until the maximum demand link itself is marked. This then forces the search to be directed somewhere else entirely. Subsequently, all the marked links become available for re-evaluation in other steps of the overall process.

5.5.2 Determining the route capacity

Once a sequence of links has been identified, it is necessary to determine the capacity of the potential route. There are a number ways in which the capacity could be determined, each resulting in slightly different route configurations. To select the volume of the link with the highest demand will normally result in vehicles operating at very low utilisation; it will also necessitate more passenger transfers by precluding smaller routes. Selecting the lowest link volume will maximise the coverage and vehicle utilisation where many vehicle capacities are available, but may result in some links being left with an inadequate number of trips to justify a parallel service within the category specifications. The number of trips considered inadequate to justify a new service is the "Minimum remaining demand," as mentioned earlier. Other measures, such as the passenger-kilometre to space-kilometre ratio could also be used. The author has chosen to keep to the simplest approach however, that of not leaving too few outstanding trips at any node to justify an additional service. The process by means of which the route capacity is determined is as follows:

CAPACITY DETERMINATION ALGORITHM

1) Is the difference between the maximum and minimum demand, in the primary direction (See Note,) less than the minimum remaining demand for the category specification?
   a) YES: The capacity is the maximum link volume. **End search.**
   b) NO: Go to step 2
2) Does the route have possible branches?
   a) YES: Go to step 3
   b) NO: Go to step 7
3) Does the route have entering branches only?
   a) YES: The capacity is the maximum link volume before the first entering branch. **End search.**
   b) NO: Go to step 4
4) Does the route have leaving branches only?
   a) YES: The capacity is the maximum link volume after the last leaving branch. **End search.**
   b) NO: Go to step 5

Note: This process may possibly be improved by testing the volumes in both directions to ensure that trips, insufficient to carry a new route, are not left on reverse direction links with a demand greater than the specified capacity.

5) The route must have entering and leaving branches. Determine the maximum link volume of the links above the first entering branch and below the last leaving branch.
6) Is the difference between these less than the minimum remaining demand for the category specification?
    a) YES: The capacity is the maximum of these. **End Search.**
    b) NO: The capacity is the minimum of these. **End search.**
7) Search the link sequence for a continuous sub-sequence in which the demand is sufficient to permit a new route according to the category specification in terms of demand and length. Does such a sub-route exist?
    a) YES: The route capacity is the maximum link volume of the links not included in the sub-sequence. **End search.**
    b) NO: The capacity is the maximum link volume. **End search.**

Once the capacity is determined, then the number of passenger-kilometres provided by the route are determined as is the outstanding demand on the links along the route, as described in the route extraction algorithm. As mentioned there, both these steps assume that, where the link demand exceeds the line capacity, the line operates at capacity. This is because the design process seeks to exactly satisfy the maximum demand segment. For all passengers to pass through this segment, all lines on the segment must operate at the specified capacity. Of course, in reality, the supplied capacity will exceed the specified capacity because of standard vehicle capacities and design utilisation factors, which force at least some spare capacity. Users will thus have the freedom to change lines.

In the case that the outstanding trips are less than the line capacity, the vehicles run partly filled but no trips remain unserved. Theoretically, all trips are eventually accounted for on all links; every desired trip can thus be made although, in the worst case, many transfers may be required. In practice, there will be limitations on minimum route length and minimum demand that may leave some trips outstanding on short high-volume sections or on low volume links.

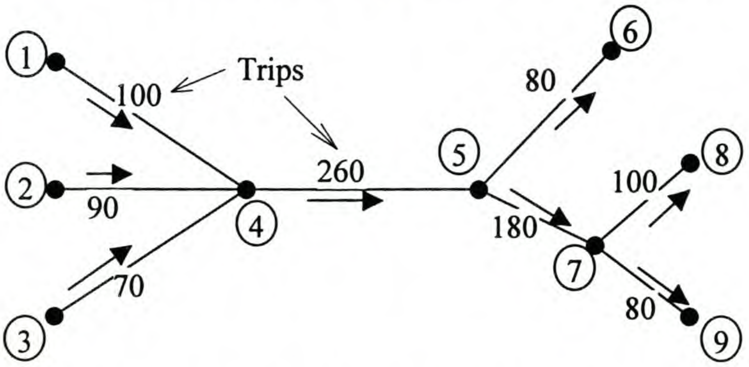
5.5.3 Potential access nodes

The route extraction program produces a schedule of nodes defining the path of each route. Many of these nodes are however, not relevant as potential access nodes for the public transport routes. In general, except at terminal points, a node is only likely to act as an access point if there are more than two active, bi-directional links, (assuming two-way links,) at a node. The route extraction process includes a sub-routine, which marks the nodes according to the active links connecting at each node, taking into account express and regular demand separately. This process does not include the mode as a criterion; i.e. pedestrian links and links of other modes are counted as active links.

This process is carried out at the beginning of the extraction process, before the link demand tables are modified by the extraction process. The results are stored in the Node table and are later used to specify the transit lines when a batch input file is created for the Emme/2 transit assignment.

5.6 A ROUTE EXTRACTION EXAMPLE

A small network as depicted in Figure 5-1 serves to demonstrate the route extraction process. The figure shows only the trips in the primary direction whilst the full link data is shown in Table 5-2. In the actual process, the centroids of the example would be regular nodes as centroidal links are not eligible for selection. The complete example is contained in the database: "REExample.mdb" on the accompanying compact disc.



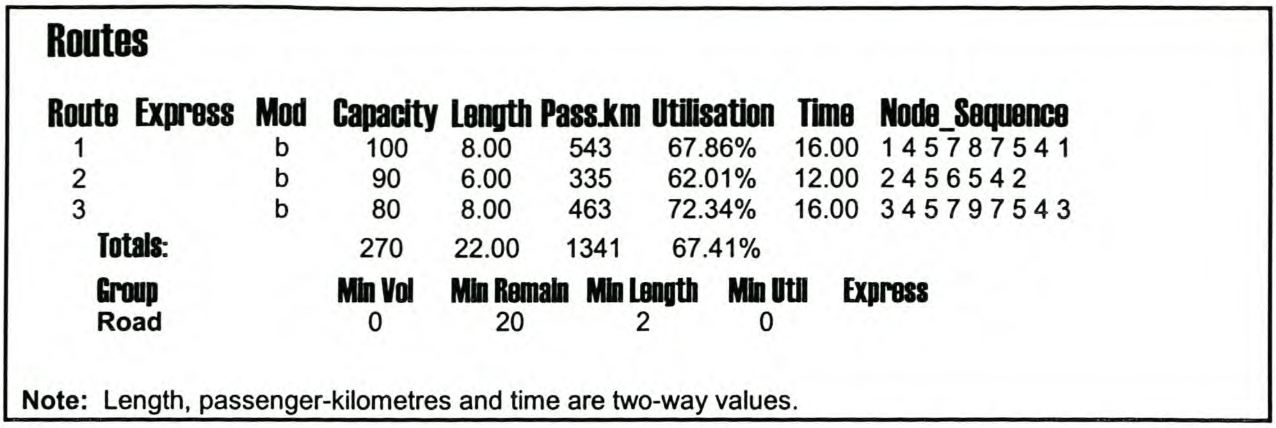
Centroids: 1,2,3,6,8,9.
Regular nodes: 4,5,7.
Trips: link volume

Figure 5-1: A simple example network for demonstrating the route extraction process.

I-Node	1	2	3	4	4	4	4	5	5	5	6	7	7	7	8	9
J-Node	4	4	4	1	2	3	5	4	6	7	5	5	8	9	7	7
Length	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Time	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Vol	100	90	70	20	20	60	260	100	80	180	20	80	100	80	40	40

Table 5-2: Link data for the example network of Figure 5-1.

The route extraction is carried out as per the algorithm presented earlier. A step by step expansion of this example is provided in APPENDIX G. The results of the computerised extraction process are shown in Table 5-3 and may be compared with the manually derived results in the appendix. The difference in the passenger-kilometres is due to rounding of the values in the proportional determination of the return trips made on each line.



Routes

Route	Express	Mod	Capacity	Length	Pass.km	Utilisation	Time	Node_Sequence
1		b	100	8.00	543	67.86%	16.00	1 4 5 7 8 7 5 4 1
2		b	90	6.00	335	62.01%	12.00	2 4 5 6 5 4 2
3		b	80	8.00	463	72.34%	16.00	3 4 5 7 9 7 5 4 3
Totals:			270	22.00	1341	67.41%		

Group	Min Vol	Min Remain	Min Length	Min Util	Express
Road	0	20	2	0	

Note: Length, passenger-kilometres and time are two-way values.

Table 5-3: Table of potential routes resulting from extraction process.
(Based, in this case, on a minimum viable line capacity of 20 trips.)

In the example of Figure 5-1, 15 return lines, (e.g.1-4-2-4-1, 6-5-7-8-7-5-6, etc.), would be required to eliminate all transfers between every origin-destination pair given that:

Equation 5-1

$$\text{Lines required} = \sum_{n=1}^{N-1} n$$

Where: N = the number of centroid nodes.

However, it can be seen that three lines, with very little spare capacity, will suffice to cover all trip combinations with a maximum of one transfer required of any user. Considering the line between centroids 2 and 6 via intermediate nodes 4 and 5: Providing 90 seats will cover all the trips leaving centroid 2 and arriving at centroid 6 whilst ensuring that no line with less than 20 seats is required to satisfy trips in the primary direction, although some passengers will have to transfer. In reality, it is rare for there to be sufficient demand between any two centroids to specifically justify a direct service and thus many public transport users are likely to have to make at least one transfer. Where the origin-destination demand is sufficient to justify a dedicated route, it will be tested in the analysis of potential express lines. If there is proportionality between origin and destination volumes, (i.e. if 100/260 of the trips from node 1 go to node 8,) then the process also minimises the number of transfers required with the given number of lines.

The result of the process is a table of potential routes specifying the length and line capacity and the node sequence. The definition also provides the approximate round trip travel time and passenger kilometres on the route. Data on minimum terminal times and other pertinent factors can be appended; either by default on all routes, or manually route by route. This allows a realistic determination of the number of vehicles required to operate the route. There is also a record of the number of times each link and node has formed part of a route and whether or not nodes have acted as route start and end nodes. This information is used to examine the siting of infrastructure as discussed in a later chapter.

5.7 BACKTRACKING

A difficult problem in the extraction of routes, using the process described here, is the elimination of backtracking. In this case, backtracking is used in its broader sense of directionality rather than simply carrying the same passengers in both directions on a link pair. This may sometimes be necessary in reality, when a route makes a detour to an intermediate destination, but is not allowed in the extraction process. (The planner must manually adjust routes to do this.) As mentioned earlier, the approach adopted in this model is to simply prevent the route from crossing itself or getting too close to the already selected links. This is done by excluding all links entering or leaving the already selected links from selection until the current route is complete. (The reverse path of a route is not affected by this limitation.) A simple example is shown in Figure 5-2.

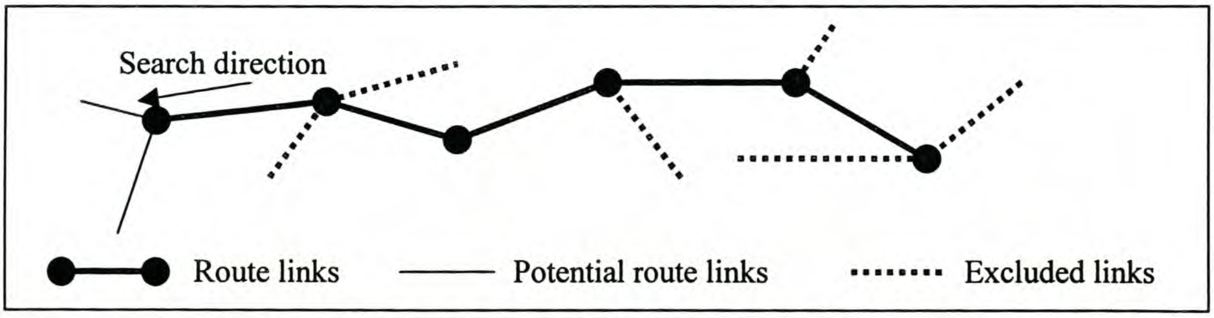


Figure 5-2: Link exclusion in route selection as a backtracking prevention method.

Within the route extraction process, whilst a route cannot use its reverse link or cross itself, it may well use a series of links that take it around in a sort of spiral or U. There is thus not any guarantee of any degree of directionality. This is not satisfactory to users. The problem is that near terminal points, significant backtracking may be necessary to access the terminal and so a directionality co-efficient type approach is unreliable because the end of the route is not known until it is reached. In a citywide model, this is not that much of a problem as the demand pattern tends to be focused to or from the central business and industrial districts. Within these areas however, the extracted routes could tend to wander since no origin-destination pairs are specified. Fortunately, unlike the example given by Rea (1972) and subsequently used by Lee and Vuchic (1999,) the number of centroids in urban models is usually limited compared with the number of regular network nodes. The demand patterns, even in the off-peak periods, are thus reasonably focused on the network. The planner must nevertheless monitor the extraction process carefully for routes in CBD areas and will possibly have to modify some routes in the CBD manually before they are subjected to the resource allocation process. This problem is also often overcome by using suitable minimum target demand and minimum remaining demand values in the route extraction category specifications.

An approach to the backtracking problem, proposed but not implemented in the route extraction program due to the complexities of programming, is as follows:

1. Once a link is added to the potential route, it is tested to see if it is going to be the last link in the sequence. If it is not:
2. A circle, centred on the start node and with a radius equal to its length, is drawn around it. This circle represents an exclusion zone. No subsequent link on the route may have a node inside the exclusion zone unless it joins the start node of the very first link. This last case will give rise to a closed loop route.
3. The next link is selected to end outside the exclusion zone and a new circle is added to the exclusion zone.

In a street layout where more or less perpendicular street intersections are the norm, this quickly forces the route extraction process away from its starting point and preceding links. This has not been implemented but is considered worth further examination as an approach to the problem.

5.8 TIDYING UP

The route extraction process is such that when it is finished the basic extraction routine, for one of a number of reasons, there is demand outstanding on some links. These links may or may not be served by or connected to defined lines. Often, these trips can be absorbed into a line definition either to the benefit of the line, or at least without making it non-viable. It may also sometimes be justified to join two or more lines that meet or overlap.

5.8.1 Outstanding trips

There are three main reasons for these outstanding trips:

1. During the extraction of a particular category, a few links at the end of the derived line did not fit the selection parameters. For example, links below the minimum demand are not considered for a route. These links are subsequently also found to be unsuitable for a route in any other category.

2. A branch with adequate demand to justify a new route appears to exist. Consequently, some trips are left on a link, or links, included in the current route. Subsequently, the branch fails to meet the criteria, usually that of length. This problem may be reduced by considering the demand in both directions on each link during the capacity determination process.
3. Short feeder links onto busier links are never selected for a route. These links do not form sequences long enough to justify a new route. These links can only be included through manual modification of the routes specified by the extraction process. This will mean creating new routes and altering the specification of existing routes.

Where possible, the outstanding trips arising out of the first two causes are captured in one or both of two ways, subject to overall line utilisation:

- Outstanding trips on links on which lines already operate are allocated to those lines. This may require increasing the line capacity. This is carried out by adding the demand to the routes with the lowest utilisation on the link being considered.
- Links with outstanding trips, at the end of lines are added, if suitable, to one or more of the lines ending at the common node. The links are assigned to the routes that will benefit most or lose least from the extension and then only if the extension will not bring the utilisation below the specified minimum.

As the code presently stands, due to coding complexity, only one route is used to absorb the outstanding trips. This can and should however, be modified so that outstanding demand is distributed to the best overall effect.

The number of outstanding trips can be minimised by using only one category and setting all the parameters at the lowest possible values. This is not always ideal however and thus the DSS carries out the check for such conditions and attempts to match outstanding trips with derived lines. As a final mechanism for examining outstanding demand, a category with zero values for all criteria can be used to convert all outstanding demand into potential routes, albeit that they are not feasible ones. These can be individually examined but must be excluded from the resource allocation process.

5.8.2 Full or partial duplicate routes and short abutting routes

As discussed in the section on capacity determination, the extraction process may generate two lines, (or more,) one of which operates fully within the domain of the other. For example, a

10km route with a capacity of 500 may fully contain another 6km line with a capacity of 60. It may be worth merging these lines. Similarly, two lines of different categories may end in a common node or overlap for a short distance. Under certain circumstances, it is preferable to join them to form one route, as this will eliminate at least some transfers without affecting the resources required. This merging may take the form of splitting the larger route so that only some of its vehicle trips go the longer route.

Given the complexities of the problem and that it is not always desirable to merge routes, the merging process must be carried out on individual merit. The Emme/2 transit assignment process can be useful in this respect, allowing detailed analysis of the lines generated by the extraction process.

It is still however, not possible to say with any certainty that all these routes can be operated. To investigate this, the goal-programming model described in the next chapter is used.

5.9 REFERENCES

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6 ALLOCATION OF RESOURCES

6.1 INTRODUCTION

The previous two chapters focused on the definition of potential public transport routes, which sought to meet customer travel path choices with only limited reference to the resources with which to provide this public transport. However, the actual provision of public transport is dependent on being able to provide and operate the necessary resources. In a multi-modal, multi-operator public-transport system, which is the context of this work, one of the central tasks is to establish which vehicles, and thus operators, to assign where. This entails the optimal distribution of resources given multiple, conflicting objectives. This is complicated by the different travel patterns prevailing at different times of day and further by the common practice of modelling one-hour periods, representative of longer periods. For example, the peak hour is modelled although the peak operating period may be as long as three hours or more.

The decision-maker wants to know how to allocate the fleet to the potential routes in each of the operating periods, (AM-Peak, PM-Peak etc.,) given his preferences for achieving certain goals. In the model presented here, only a limited number of goals are included since these inherently incorporate a much wider range of issues. The decision-maker can select the priority of each of these goals.

Associated with our network model and the resulting output, is a database of the public transport fleet and regional policy considerations. The fleet information includes, for each vehicle type:

- operating cost per kilometre
- operating cost per hour
- fuel type
- fuel consumption rate
- vehicle capacity
- minimum feasible headway
- desired load factor
- exhaust emission data
- the number of such vehicles available
- Etc.

The policy data will include preferences for fuel type, average route frequencies, pollution targets, and so on. These policies need to be weighted or prioritised in terms of local objectives.

In fact, there may be several data files, each with alternative public transport system definitions. When the database is created, the existing public transport network included in the Emme/2 model can be imported directly into the database along with the associated information. Similarly, several different policy and focusing options may have been used in the network and route extraction models, each resulting in different network configurations. Each of these can be subjected to the same resource allocation process and the results compared.

The potential-route data and fleet database are brought together in a goal-programming model, which seeks to match the fleet to the routes within the constraints and policy goals specified. The author has used a weighted goal-programming model and the modelling language, LINGO by Lindo Systems.

In particular, Lingo Super, with an educational licence has been used. This version allows:

Constraints	1000
Non-linear constraints	0
Variables	2000
Integer variables	200

Lingo incorporates a model generator and thus requires only a template model, irrespective of the number of routes and vehicles to be evaluated. All data and parameters can be stored in the database and modified without direct manipulation of the goal-programming model. The software licence used here can deal with a limited number of real, general integer and binary variables. This can be upgraded, directly or through a number of stages, to support an unlimited number of variables and constraints, to handle non-linear programming and to include additional solver algorithms for specific problem types. In a very small system, the goal programming could possibly be carried out using one of the spreadsheet packages, such as Microsoft Excel, thus eliminating the need for additional software.

(The accompanying CD contains the file "Lingo6.exe" which will install a demonstration version of the package on a computer running any of Windows 95/98/NT. The demo version cannot solve all the examples, which have too many integer variables for the Demo licence. It can however, be used to view the models and the solutions saved on the CD as well as to run smaller examples. The model and result files can also all be viewed with any text editor.

After completion of the first draft of this dissertation, some problems were picked up with the use of the Lingo package as compared with some other software. For commercial application of the DSS, other software would have to be considered.)

It is possible to make the goal-programme model invisible to the user of the database, invoking it as a hidden module that updates the database records. Modification and testing of the model is somewhat more difficult when run in this way and the goal-programme model has thus been incorporated as a standalone model with the model script stored in the database for portability.

6.2 GOAL-PROGRAMMING

Goal programming is the general case of the better-known linear programming technique for decision-making. The basis of the method is that a system of simultaneous linear equations and inequalities is solved in such a way as to determine the best solution to the problem under investigation. This assumes that there are several possible solutions to the problem, some better than others when measured with respect to certain criteria. Linearity is a requirement for what are termed linear models, which are the easiest to solve. There are however non-linear solvers using modified versions of the linear-solvers, Lingo being one of them. Non-linear models may have several local optima aside from the global optimum and the solver may stop at a local rather than the global optimum in its search. Consequently, non-linear models are inclined to be less robust and often absorb considerable resources in their solution.

A linear program model comprises two main components:

- A single factor **objective function,** such as cost, profit, or time, which is minimised or maximised.
- One or more of a number of **constraints** of the form:

Equation 6-1

$$\sum_{ij} a_{ij} x_i \leq b_j$$

or

Equation 6-2

$$\sum_{ij} a_{ij} x_i \geq b_j$$

or

Equation 6-3

$$\sum_{ij} a_{ij} x_i = b_j$$

The solution, if there is one, is such that no constraint is broken.

Goal-programme models deviate from linear program models in that they may or may not have fixed constraints, such as shown above, but also have one or more goal statements. This gives rise to one of the chief differences between linear and goal-programmes. The linear program may not have a solution where the goal-programme will have a solution albeit not one conforming exactly to all the goals, which are of the form:

Equation 6-4

$$\sum_{ij} a_{ij} x_i + n_j - p_j = b_j$$

Usually, the decision-maker wishes to avoid either over or under achievement of the goal value b_j. Under-achievement is represented by the value n_j while p_j represents over-achievement of the target value. These are known as deviational variables and may only have non-negative values. Goal-programming models have an objective function, like the linear program models, but this objective function essentially seeks to minimise some function of the deviational variables. The form of the objective function depends on the goal-programming variant being used.

Goal-programming models can take a number of forms that are related to other multiple criteria decision-making techniques. The three primary variants of goal-programming models, (Romero 1991,) each with slightly different properties, are:

- Lexicographic or Pre-emptive goal-programming (LGP.)

  The problem is solved by means of a series of models. These are solved for each goal, in order of descending priority, using the results of the higher priority as constraints for the lower priority. The objective function has the form:

Equation 6-5

$$\text{Lex Min } a = [h_1(n,p), h_2(n,p), \ldots, h_q(n,p)]$$

Where: h_1 = Function of deviational variables of highest priority.

h_2 = function of deviational variables of second highest priority, etc.

- MinMax goal-programming (MinMax GP.)

  In this form of goal-programming, which is used in a secondary role in the presented model, the maximum deviation is minimised. This form of goal-programme has a slightly different structure, which over and above constraints similar to those shown in equations 1-4, includes constraints of the form:

Equation 6-6

$$\alpha_i n_i + \beta_i p_i \leq d$$

Where: α_t and β_t are the weights associated with the deviational variables n and p for each goal, i.

d = the maximum deviation.

The objective function is:

Equation 6-7

$$Min\ d$$

- Weighted goal-programming (WGP.)

  In this case, the sum of the weighted deviations from all goals is minimised. This form of goal-programme is the primary form used in the resource allocation process and has the general form:

Equation 6-8

$$Min \sum_{i=1}^{k} \left(\left(\alpha_i n_i + \beta_i p_i \right) / T_i \right)$$

Subject to: $f_i(x) + n_i - p_i = T_i$

$x \in F$

$x \geq 0 \quad n \geq 0 \quad p \geq 0$

Where: α_i and β_i are the weighting factors of the negative and positive deviations $\mathbf{n_i}$ and $\mathbf{p_i}$, from the target value, $\mathbf{T_i}$, of the attribute **i** being considered. **F** is the feasible set for the variable **x**.

In goal programming, usually, only one of the deviational variables for each goal needs to appear in the objective function. For example, if there is a profit-loss goal, then any amount of profit is acceptable but loss is undesirable. Only loss need therefore be included in the objective function. It is important to include both deviational variables in the goal statements however; otherwise, they may reduce to simple constraints resulting in a sub-optimal solution. If profit is not allowed for, a solution will always be found with a profit of, or less than, the target value although a solution may exist with a better profit whilst meeting all other objectives.

Dividing the sum of the weighted deviations by the target value results in a per-unit comparison of the deviations rather than an absolute value comparison that would be distorted by differences in magnitude and units. This is referred to as normalisation and reduces but does not eliminate all the problems associated with differences in magnitude, as is discussed by Romero (1991.)

As it happens, in the resource allocation problem developed in this chapter, the normalisation process introduces undesirable properties. Fortunately, the omission of the normalisation factor, except in the case of the monetary goal, actually introduces a positive benefit in the process, creating an inherent set of goal weights which significantly simplify the setting of these weights.

One of the requirements for a good linear or goal-programme is that the range of the left-hand side coefficients and right hand side limits or targets should be limited. Too great a range of variable coefficients may distort the importance of certain variables and the solver may introduce significant rounding errors, which will alter the solution. Lingo recommends that the maximum factor relating smallest and largest coefficient is one thousand. For this reason, it is sometimes necessary to change the units of measurement of particular variables. For example, if the monetary values amount to millions of Rand and the frequency variable is typically well under one hundred, then it is preferable to model the monetary amount in units of one million.

Finally with respect to goal-programming in general: The goals set by the planner should correlate with the resources. In other words, do not set clearly unrealistic goals. Whilst a properly structured goal-program will eventually find a solution, it may require hundreds of times the effort to solve compared with a model having realistic goals. For example, do not set a target frequency of twelve vehicles per hour when the fleet size is unlikely to meet demand and allow for more than four vehicle trips per hour on average. If the results of the allocation process indicate that improvements may be possible, implement them gradually. This will in all likelihood lead to more confidence in the result and probably will not take much longer to achieve.

6.3 THE PUBLIC-TRANSPORT RESOURCE-ALLOCATION PROBLEM

There are a number of considerations in the resource allocation process. The most important of these is the need to keep the allocation model as simple as possible. The model may need modification for each project and simplicity means that the planner does not need to become an expert in operations research techniques before being able to use the system.

A second motivation for simplicity is that the model size increases rapidly as the number of constraints, routes, and vehicles increases, slowing the solution process. Every additional constraint will add some multiple of the routes, vehicle types, and periods to the total number of constraints.

Given that it is quite common for a few objectives to dominate the allocation process, the inclusion of many secondary objectives serves little purpose. The philosophy is thus that of only including fixed constraints and decision variables that are considered of primary importance. The foremost of these are:

- Meeting the travel demand.
- Achieving the policy service frequency.
- Limiting changes to the fleet composition.
- Minimising the overall cost and thus the minimum viable fare.

This simplification can be justified when the logic of the resource allocation process is considered. The primary objective of public transport is to provide sustainable transport for the maximum possible number of people, particularly those without their own transport. (Sustainability implies that the transport must satisfy an actual demand.) Providing this public transport produces costs and revenues and in some way, all goals and constraints impact somewhat on the cost of providing the service. This cost comprises a combination of factors as diverse as import tax on imported vehicles and components, the cost of labour and the price of different fuel types. Thus, simply meeting the demand and minimising the cost already provides a reflection of the typical decision-makers secondary goals.

For example, in respect of pollution and fuel type: Where there is a true attempt on the part of the central government authority to favour one fuel type over another or to limit energy use, this should be reflected in the fuel price. Since the operating costs are reflective of the fuel price, promotion of energy efficiency and a preferred fuel type are inherently incorporated into the model. Of course, the planner may wish to introduce these as separate items, which can be done at the cost of additional computing time and complexity. These days, pollution is a critical issue and so the choice of fuel type may be best modelled by using a measure of the different pollutants given off per seat-kilometre by the different vehicle types. This may give rise to a degree of double counting where the fuel price already reflects pollution costs. An example of how this form of goal can be modelled is given but is not implemented in the model.

In a similar way, the use of smaller vehicles is likely to increase the total number of people employed. If job creation is a planning criterion, then giving weight to the under-utilisation of the available fleet can be used to create as many jobs as possible within the system.

Ultimately, satisfying the demand is a truly overriding factor in an urban public transport system. If it were not, the chances are good that there would be no public transport service at all. There are circumstances where public transport does operate at a profit and then, for some operators, there is a profit motive. This usually leaves many people without transport however. The only reason that the demand is not treated as a fixed constraint is that the resources available might not be adequate to cope with all the demand. In this circumstance, the model would fail without providing any useful information for improving the system design. As it is, a system can be designed, given existing resources, in which some travellers may have to adjust their travel patterns but in which as many travellers as possible are satisfied. The planner can then use these results to gauge how best to improve the resources to meet all the demand.

Accepting that satisfying the demand is the dominant factor, certain other goals become relatively meaningless, especially when taken in combination. If all demand is satisfied, no one is going to complain about increased service frequency, which will naturally be limited by the cost goal. The over-achievement of the frequency goal can thus be given a zero weight. The same cost condition will also limit the oversupply of capacity.

In a similar way, under-utilisation of the fleet is also usually irrelevant providing that the demand is satisfied given the earlier proviso in respect of job creation. Interestingly, over-utilisation of the fleet is also of limited concern. In the immediate case, it is of course a problem, but when it is favourable to do so, additional vehicles of a particular type can be added to the fleet, selling those that are less suitable. The vehicle cost will reflect the government's view on importation through import tax and local content will be favoured in the vehicle price and thus overall operating cost. Since the operating cost of each vehicle type includes the cost of capital, little other input is necessary and thus vehicle availability is only important for short-term planning decisions. There are of course complications associated with this – mostly related to immediate availability of capital and operator willingness to change to new vehicle types. These are however, business and not technical problems. The model does allow the imposition of a vehicle availability constraint for short term planning.

Having stressed the need for simplicity, there are cases where additional modelling complexity may be required. Within the route extraction process, the minimum route length for each mode is typically the acceptable walking distance. In the resource allocation process, a vehicle based minimum route length requirement may exist. For example, high capacity, seatless vehicles should only be used on short trips. Thus, such vehicles may be limited to routes that are shorter in time or distance than some target value. On the other hand, luxury buses with catering facilities may be wasted on short routes where there is insufficient time to make use of the expensive equipment on the bus. Again, the method is demonstrated but not implemented.

There are factors, which are beyond the scope of this form of modelling. Theoretically, a vehicle used on a route, for only part of the operating period under evaluation, could be used elsewhere for another part of the period. This would reduce the overall number of vehicles required and thus the cost. This is significant where all the routes are operated by one concern. However, in the context of this dissertation, there are many operators and thus run cutting is less likely to occur. Detailed analysis using one of the specialist programs available for the purpose, such as Hastus (Giro 1998) can be used to refine the vehicle needs and costs if necessary.

The allocation of resources to the non-road modes is usually highly constrained by infrastructure and available resources, this chapter thus discusses the resource allocation process only from the perspective of the road modes. The model is not mode dependent and can be used for any mode but has been constructed to deal with only one mode at a time to minimise the computer resources required. This is feasible because the resources are not generally transferable between modes. The database is constructed so that the data passed to the Lingo model contains only road mode routes and vehicles. The planner can change to another mode in the database and rerun the Lingo model. The total costs and revenues are available in the database after all active mode groups have been processed. This particular approach does not consider the subsidy across all mode groups concurrently and the planner thus has to apportion the subsidy according to some formula, such as the passenger-kilometres, for each mode and operating period. Because the model allows the subsidy to be treated as a goal or a constraint, the apportionment need not be binding on the solution.

6.4 PREPARING THE MODEL

The goal-programme model, given in full in APPENDIX L and as Resources.lg4 on the CD, has been developed using the Lingo package. This package generates the objective function, goal statements, and constraints from a template model and the route and vehicle tables of the decision support system database. In order to do this; the model comprises a number of distinct sections:

- The definition of the decision variables and the attributes of the various elements of the system.
- The statement of the goals, constraints, and objective function.
- The data input and output section.

Within the model itself, these sections are not as neatly separated, as sometimes the variable definition is reliant on the availability of some of the data and so some data precedes some of the definitions. The following presentation does however follow the listed order.

Although it results in the loss of some diversity in the modelling process, the author has chosen, after extensive experimentation with non-linear models, to use a linear model. Examples of the possibilities using non-linearities will be presented where relevant but these have not been implemented in the working model.

6.4.1 The decision variables and system component attributes

In order to generate the full model from the template model, Lingo uses "Sets." A set describes a particular category of objects that are indexed with respect to the set. In the public transport resource allocation process, the primary sets are the "Periods," the "Routes" and the "Modes" or vehicles. These are used to create another set, "Lines," which combine the routes and vehicles in each period. The index is the name or number of the period, route or vehicle type, etc. In each case, the set specifies the attributes common to all objects in the set. The actual values for each item, route, vehicle type etc, are input in the data section. Over and above these sets, there are also a number of "global" attributes for the entire system. There are two categories of attribute:

1. Those for which the values are **supplied to** the goal-programme model. These are given in **bold** text.
2. Those for which the values are **determined by** the goal-programme.

The sets and their attributes are discussed in the following sections.

6.4.1.1 The Periods

Public transport syster :d with different cha aracteristics for each of a number
of different operating ıy, these periods ma ıy be:

- the AM-pe:
- the PM- peak
- the day off-
- the nigh t off-peak

There may be additioı ays and for weeken d days and special days, such as
public holidays. In tł ansport, a one-week k period is the smallest complete
cycle, including as it ekday operating per riods and the weekend operating
periods. It is unusı ıblic-transport-syste: m operating-schedule for other
temporal variations, sı ;. The goal-program mme model is constructed in such
a way that these perio simultaneously. Thi is allows the determination of the
cost of a full operating

There is a second and n for simultaneous consideration of all the operating
periods, one that pose delling process. Al lthough any one operating period
may be best operate allocation of resou rces, this may not be the best
configuration for the ıting periods. For example, the AM-peak optimum
design may include o he day off-peak ma y include a mixture of large and
small vehicles while ıy only need small vehicles. Increasing the cost of
operating the AM-pea l vehicles may impr ove vehicle utilisation and reduce
the overall system cos reason for this unc ertainty is that the operating cost
per hour is a function urs worked and the distribution of those hours. For
example, operating ei a day may be chea per per hour than twelve hours a
day in two six-hour s ıumber of hours is u p by fifty percent, thus lowering
the capital costs per h t shifts, and possibly y a second driver, may result in a
higher hourly cost.

Given these considera ermination of the ho urly cost is clearly impractical in
a model such as thi the average operati ng hours for each vehicle type
introducing a non-line Consequently, in thi is model, a two-pronged approach
has been taken. First ıade in the model e nabling the update of the vehicle
cost model discussed The revised hourly operating costs for each vehicle
type are then used for he allocation proces s.

Secondly, it is possible to set the minimisation of the total number of vehicles used in the system as a goal. [It is also possible to minimise the difference in numbers between the vehicles of each type across all periods.] The logic behind this is that the smaller the fleet used, the greater the individual vehicle utilisation is likely to be and is based on the assumption that costs are minimised in the process. The approach tends to prevent only buses being selected for one period and only taxis for another as the result will be more vehicles than are required if taxis and buses are used in both periods. Some allowance is then made for additional hourly costs during the night and weekend periods associated with increased staff salaries.

The first step is the declaration of a set defining the operating periods to be evaluated. The operating period is an attribute of a route.

The Periods Set has six attributes aside from its index name that may be, for example: AM, PM, DY, NT etc.:

Start_Time — the start time of the period using decimal 24-hour time. E.g. 16.5 ≈ 16h30.

Tlength — the length of the period in decimal hours. This is used for cost analysis.

ho — design period – operating period factor described in Equation 4-7, Section 4.3.5.2 of Chapter 4.

MinDem — the minimum peak-section design-hour demand from amongst all the routes in the period

PFreq — the number of times in the resource allocation period that this operating period occurs.

PCost — cost penalty factor on the hourly cost for operating a period. Night and weekend operating periods may have higher hourly operating costs to allow for additional staff costs.

The duration of an operating period poses a problem. As mentioned, it is common practice to model the general transport network only for the peak hour whereas the public-transport operating-period may cover several hours. The result is that the total number of passenger kilometres for an operating-period is not correctly represented by the network model using a one-hour period. It is also possible that the peak-hour for the public transport system is not the same as the peak-hour for the private transport network. It is further possible that the peak-hours for different routes are not concurrent. With sufficient data, the network model described in

Chapter **4** could be used to determine both operating period totals and peak hour requirements. The level of data required is often not available however, and another approach is thus required.

The average values for the period are not useful, as there is usually a peak demand during a short interval within the operating period, with lower demand before and after that peak. Since the customers wish to travel as close to their time of choice as possible, the system must meet the demand in that peak hour if not in a shorter peak period. For the remainder of the period, the routes will operate at lower utilisation but are kept unchanged in order to simplify matters for both the customers and the operators. To provide an estimate of the actual passenger-kilometres travelled for the entire operating period, the factor "ho," the ratio of design-hour to operating-period demand is used. The determination of this value is discussed in Chapter **4**, Section 4.3.5.2.

This problem extends to the days of the week, when some days have different travel patterns to others. (For example, Monday may be different from Tuesday.) It is not desirable to change the route patterns on a daily basis and so the busiest weekday period should be used for the design. Public transport also operates on weekends and this has an impact on the total cost. Usually the fleet requirements are not a problem, the weekend demand being much less than the weekday demand. Not all operating-periods arise with equal frequency. For example – a weekday morning peak will occur 5 times a week. A Saturday morning operating period will occur once a week. When designing for one day, a period will only occur once. This gives rise to the "PFreq" variable, which tells the model how many times to count the cost of the particular operating-period in evaluating the full public transport design period which will normally be one week.

As far as possible, it is preferable to increase the value of PFreq and reduce the number of periods. Thus, if the morning and afternoon peak periods were sufficiently similar, the same design, both in practice and in the modelling process, would be preferable to two different designs. In the modelling process, this can significantly reduce the effort required to find a solution since the reduction in the number of periods reduces the number of integer variables.

Arising from these different periods is the likelihood that the time based operating costs will be different in different periods owing to night shift and weekend salary differences. The "PCost" variable is used to deal with this.

6.4.1.2 The Route Sets

There are two sets required to define the routes. Because a route may operate in more than one period, the full route index needs to include the route index and the period index. For example, there may be a route defined as (AM, 1) and another defined as (PM, 1). These routes must both be considered but will not use resources at the same time and therefore must be seen as separate routes, even if they are identical in all other respects. The first set used to define the routes is the AllRoutes Set. This is indexed on the route numbers and has only one attribute:

Period — the period in which the particular route operates.

With this information, the model is able to generate the second and main Routes Set which gives all the remaining attributes for each route. This Routes Set is a derived set in which a unique route definition is created for the goal-programme model such that the route index includes the period and name of the route as separate indices, necessary for the construction of some of the goal statements. The form of the statement for this set is:

```
Routes(AllRoutes, Periods )|(Period(&1) #EQ# (&2)):
```

This can be read as: The index of this route is (Route, Period) where the AllRoutes attribute Period equals the index of the set Periods. The index number is represented in the template by the symbols (R,P) Thus, the demand attribute for a route is written as Demand(R,P) and is interpreted as the peak section demand on route R during period P. The route attributes for each route and period are as follows:

Demand — the design-period average peak-section demand on route.
Demandu — the under-supply of capacity on the peak load segment.
Demando — the over-supply of capacity on the peak load segment.
DesCap — the design capacity achieved on the route.
TotCap — the total capacity achieved on the route.
Freq — the desired route frequency, the policy frequency.
Frequ — the under-achievement of the policy frequency.
Freqo — the over-achievement of the policy frequency.
TotTrips — the total number of vehicle trips provided on the route.
Nv — the total number of vehicles used on the route.

Tlb[1] — the lower bound frequency for the route, usually zero except where a route is considered to take priority over other considerations.

Tub[2] — the upper bound of the number of vehicle trips on the route. This must be at least one unless the route is to be excluded from the allocation process. A limitation on the maximum frequency usually associated with the minimum headway arising from either vehicle or fixed infrastructure.

PassKm — the passenger-kilometres estimated for the route. Passed to Lingo in units of thousands of passenger-kilometres.

Fare — the fare, in Rand, to be charged per kilometre on the route. Fare may be different for different routes and operating periods.

Revenue — the revenue expected on the route.

RouteCost — the expected cost of operating the route.

Length — the two way route length.

CycTm — the cycle time for the route. The cycle time is dependent on the traffic conditions during the period. **NB: It is important that the cycle time should have been adjusted to allow for boarding time along the route. Failure to do so may result in an under-specification of the number of vehicles required and thus of the costs.**

Types — target number of vehicle types on route.

Typeso — number of vehicle types over target assigned to route.

Typesu — number of vehicle types under target assigned to route.

MaxLen — Maximum length of vehicle that can be accommodated on route.

MaxHeight — Maximum height of vehicle that can be accommodated on route.

Notes:

1. The lower bound must be kept at zero except in cases where a route is obligatory at any cost.
2. The upper bound on the number of vehicle trips should be kept as high as possible. When there are length or height restrictions on a route, a large number of small vehicles may be required and too low an upper bound on the frequency will possibly lead to a sub-optimal solution. The DSS automatically determines the upper and lower bounds required to meet the demand with the available fleet. The lower bound is applied by modifying the model code.

6.4.1.3 The Modes Set

The Modes set specifies all the vehicles available for operating the routes. These may or not be vehicles actually in the current fleet. In other words, a stock value of zero is acceptable if a vehicle type is not in the fleet but could be obtained. In theory at least, each vehicle type could be representative of an operator as well, thus assigning operators and vehicles to routes. In practice, this leads to an unreasonable number of vehicle types and thus constraints in the model, which then becomes cumbersome and slow to solve. The specific allocation of operators to routes is thus dealt with separately.

The different vehicle types are denoted by the index variable V. Thus, the stock of vehicle V is written as Stock(V).

Stock — the number of vehicles of type V available. Can be zero.
Lf — the load factor to be applied to vehicle type V.
Capacity — the total capacity of vehicle type V.
HrCost[1] — an estimate of the cost per hour for vehicle type V.
KmCost — the cost per kilometre for vehicle type V.
VehLen — length of vehicle.
VehHeight — height of vehicle.
TvehHrs — the total vehicle hours operated by vehicle type V. Used in the database to determine the average operating hours for each vehicle type.

Notes:

1. The cost per hour is a rough estimate because it is not known in advance how many hours and in what pattern the hours will be distributed. The actual hourly cost is a function of the total number of hours actually worked and their distribution over the day.

6.4.1.4 The TempStock Set

TempStock is an abbreviation for temporal stock. This is a derived set used to allow the available vehicles to be used in each period, independently of their use in another period. This may be an over simplification inasmuch as that switching route has a cost implication. Usually however, the periods exist because of distinctly different demand patterns and volumes. Consequently, it should be technically feasible to make the change from one period to the next allowing that either, some vehicles are on standby or, some have finished on one route before the next period's operations commence. The set is a combination of the periods and the modes, giving rise to a set definition:

TempStock(Periods, Modes):

Tempstock has the following attributes which use the index (P,V) to distinguish them:

Stocku	— the number of vehicles of type V not required during the period P. This can be interpreted as the number of vehicles remaining free for use.
Stocko	— the number of vehicles of type V that it is desirable to obtain for period P.
NVehs	— the number of vehicles of type V operating in period P. Used in the database to determine the average operating hours for each vehicle type.
Vdiffo[1]	— the difference in the number of vehicles of type V operating in period P+1 as opposed to period P. This term is >0 if Nvehs(P)<Nvehs(P+1) or = 0 otherwise.
Vdiffu[1]	— the difference in the number of vehicles of type V operating in period P as opposed to period P+1. This term is >0 if Nvehs(P)>Nvehs(P+1) or = 0 otherwise.

Notes:

1. These terms used in combination give the linear equivalent of the absolute value of the difference in the number of vehicles between the two periods.

6.4.1.5 The Lines Set

The Lines set is a derived set, made up from the Routes and Modes sets. It provides the attributes describing the public transport lines that will most closely meet the goals of the decision-makers. The Lines set has a triple index specifying the routes, periods, and modes used. Thus the variable indicating the number of trips of vehicle type V on route R during period P is written as Trips(R,P,V). This set has the following attributes:

Trips	— the number of trips of vehicle type V on route R during period P.
Vehs	— the number of vehicles of type V required on route R during period P.
X	— a binary integer that equals 1 if a vehicle type V is used on a route R during period P, and 0 if not.

6.4.1.6 Global attributes

Not every system attribute is associated with a particular set. There are a number of values not associated with a specific set. The important ones are:

NetCost — the total cost of operating the public transport system minus the total revenue from the customers. The NetCost may be negative.

Subsidy — the amount, over and above revenue from the customers, that will have to come from external sources to cover the system's total operating cost.

Profit — the surplus revenue from the system at the proposed fare.

TotalCost — the total cost of operating the system.

TotRevenue — the total anticipated revenue from the system.

TotPassKm — the estimated passenger kilometres travelled on the system. Measured in thousands of passenger-kilometres.

These global attributes allow several additional and useful calculations to be performed, but externally to the goal-programming model, as they create non-linearities. The Lingo model perceives any attribute that it calculates as a decision variable and multiplication or division of two or more such variables, or any power of a decision variable introduces a non-linearity. An example is that the TotalCost and TotPassKm values can be used to determine the breakeven fare with or without a subsidy. The calculation introduces a non-linearity and so the break-even fare is only available within the decision support system database after the goal-programme has been run.

6.5 THE GOALS, CONSTRAINTS AND OBJECTIVE FUNCTION

As mentioned earlier, there are a number of basic goals to be met by the public transport system, usually with some degree of priority associated with each goal. There are many more possibilities than those listed, but the planner must consider the value of including them in the model. Those specifically included in the model and discussed here are those listed earlier:

- Meeting the travel demand.
- Achieving the policy service frequency.
- Limiting changes to the fleet composition.
- Minimising the overall cost and thus the minimum viable fare.

A brief note before proceeding: The Lingo package interprets $\leq$ and $<$ as exactly equivalent and similarly for $\geq$ and $>$. This should be kept in mind when reading the constraint statements.

6.5.1 Demand

One of the chief objectives of the public transport system is to provide particular transport products in sufficient quantity to meet the demand. The products are seats or spaces on particular routes at particular times. The product is perishable and too much should not be produced. We have already specified the products in terms of the demand and many other characteristics during the network modelling and route extraction processes. Now the production system needs to be set up allowing that a range of products is competing for the resources and that the products can be produced, using the production equipment in many different configurations, some better than others.

In terms of the product demand, we set the following goal:

> For each route, at least meet the demand, if possible, but do not provide unnecessary excess capacity.

This can be written as:

For each period (P), route (R) and vehicle type (V):

$$\Sigma_V(\text{Trips}(R,P,V) * \text{LF}(V) * \text{Capacity}(V)) + \text{Demandu}(R,P) - \text{Demando}(R,P) = \text{Demand}(R,P)$$

Where:

Trips(R,P,V) = trips made by vehicle type V on route R during period P. A vehicle may make one or more trips, depending on the cycle time on the route. Trips are equivalent to vehicle departures and are thus required to be integer values.

LF(V) = load factor for vehicle type V.

Capacity(V) = total capacity of vehicle type V.

Demand (R,P) = Design-period average peak section demand.

Demandu(R,P) = under supply of capacity route R.

Demando(R,P) = over supply of capacity on route R.

In the objective function, the minimisation of the under supply of capacity is an important factor. Over supply, whilst relevant, does not need to be included because every seat provided costs money and the cost minimisation will limit the over supply.

There are a number of other values of interest to the planner, which are associated with the provided demand. Given the assignment of particular vehicles at particular headways, it is important to the evaluation of the results to know the actual design capacity and the total provided capacity. The design capacity is the capacity of the line given the applied vehicle load factors and may be higher or lower than the peak demand. The total capacity is the line capacity ignoring the vehicle load factors, and thus higher than the design capacity. If the total capacity is greater than or equal to the peak demand, then in spite of not meeting the target design conditions, the assignment will nevertheless suffice if no additional resources are available. These values are determined as follows:

For each period P, route R and vehicle type V:

$$\text{Design Capacity (R,P)} = \Sigma_v \text{Trips(R,P,V)} * \text{Lf(V)}* \text{Capacity(V)}$$

And:

$$\text{Total Capacity (R,P)} = \Sigma_v \text{Trips(R,P,V)} * \text{Capacity(V)}$$

The total capacity of the system is an interesting result. If the public transport system is designed with any intention of using it as a form of emergency transport, then the total capacity of the system is of importance. In some circumstances, it may be justified to set a minimum constraint value on the total capacity. This may be used in conjunction with a similar constraint on the minimum total number of vehicles used to ensure capacity for an emergency. Running the allocation process with and without these constraints will provide an estimate of the cost of providing for such an emergency.

The goal statements reflecting demand are written in such a way that it is possible to have fractional vehicle capacities and design volumes. For example, if the load factor is 0.9 and the total capacity is 14 then the model will use 12.6 as the design value. This is not a critical issue although it may have an impact on the overall results as setting the design capacity of the vehicle at 12 may necessitate additional vehicles. With the fractional value, either 12 or 13 passengers must actually be carried but in either case, the vehicle will be able to carry the peak demand. Should the planner wish to be conservative in this respect, the statements can be modified by replacing the term:

Lf(V)* Capacity(V)

With the term:

@Floor(Lf(V)* Capacity(V))

This will return the integer part of the product, 12 in the case of the above example.

6.5.2 Frequency

An important aspect of customer service in public transport is service frequency. Too low a frequency limits the customer's choice of travel time and may cause him or her to choose another means of travel. Associated with service frequency, is waiting time, which, as discussed in the previous chapter, can be reduced by synchronisation of the various services, which is simplified by introducing a common minimum frequency to the entire system wherever possible. From a user point of view, the higher the frequency of service, the better. However, increased frequency with a given vehicle size, once the demand is met, will definitely increase net costs. It is further likely that increasing frequency by using smaller vehicles to meet the demand will also result in increased total costs but to a different extent, depending on the vehicles, the demand, and the cycle time. This is because time based costs, such as driver wages, tend to form a large portion of the total cost of operating and increase in proportion to the number of vehicles required.

Ideally, we also wish to maintain a service frequency that uses integer multiples of 60. Sometimes, it may be justified to run a service in which two vehicles leave say 15 minute apart and then no further departures take place for an hour or more - to accommodate work start or end times. This however is a detail to be evaluated at the final stages of route and crew scheduling, not during initial route and vehicle configuration.

Not all these factors can be directly introduced into the goal-programme. The basic concept of a minimum service frequency as a mechanism for improving customer service can however, be readily incorporated as follows:

For each route attempt to at least meet the policy frequency.

In modelling terms:

For each period P, route R and vehicle type V:

$$\Sigma_V(\mathrm{Trips}(R,P,V)) + \mathrm{Frequ}(R,P) - \mathrm{Freqo}(R,P) = \mathrm{Freq}(R,P))$$

Where: Trips(R,P,V) = trips made by vehicle type V on route R during period P. Only whole trips are allowed.

Frequ(R,P) = under-achievement of policy frequency for period P on route R.

Freqo(R,P) = over-achievement of policy frequency for period P on route R.

Freq(R,P) = policy frequency for period P on route R.

Usually, the planner is only concerned with the under-achievement of the policy frequency. There may however, be some value in limiting excessive frequencies on some routes in favour of an alternative distribution of the fleet to give more consistent frequency across all routes. Balancing the frequency across all routes is achieved by using the MinMax form of goal programming with the statement:

For all routes R and periods P:

$$\Sigma \text{ Frequ}(R,P) + \text{Freqo}(R,P) < \text{MaxFreq}$$

The MaxFreq term could then be minimised in the objective function. This particular form is demonstrated in the example Resources2.Lg4 on the CD. In order to balance only the over achievement of policy frequency, one eliminates the Frequ term from the above equation and adds it and the MaxFreq term, now reflecting only the over achievement of frequency, to the objective function.

The path that has been followed in this model is to allow the planner to promote excess frequency on larger rather than smaller demand routes. This is achieved through the inclusion of Freqo(R,P) in the objective function with a heavier penalty for small routes than for large ones.

$$\text{MinDem}(P) * \text{Freqo}(R,P) / \text{Demand}(R,P)$$

Where: Freqo(R,P) = the oversupply of frequency on the route in question.
MinDem(P) = the minimum demand in the period.
Demand(R,P) = Demand on route in question.

The effect of this is that for low demand routes, the weight of the Freqo term tends to one whereas for high demand routes, the weight tends to some small number, less than one.

There is often also a limit to the minimum headway and this must be placed in the model as a fixed constraint. In the model, upper and lower bounds are specified. This typically has the form:

For each period P and route R:

BND(Tlb(R,P), TotTrips(R,P), Tub(R,P))

Where:

BND = is a bounding function of the form: (lower bound, variable, upper bound).

TotTrips(R,P) = the total trips on route R and thus the frequency when working in units of one hour.

Tlb(R,P) = the minimum allowable frequency on the route. This is set to zero except where a route must be operated under any circumstances.

Tub(R,P) = the maximum allowable frequency on the route. This is usually dependent on fixed infrastructure capacity.

Given that:

For each route R and vehicle type V:

$$\text{TotTrips}(R,P) = \Sigma_v \text{Trips}(R,P,V)$$

The upper bound on the number of vehicle trips is set in the database as:

$$\text{Tub}(R,P) = \text{MIN}(\text{RoundUp}(\text{Demand}(R,P)/(\text{LF}(V)*\text{Capacity}(V)),\text{Technical Max})$$

Where: The vehicle used in the calculation is the one with the lowest capacity.

6.5.3 Vehicle availability

As in meeting the demand, it was desirable to produce as close to the correct quantity of each product as possible, so it is desirable to maintain only the fleet needed to just produce the correct amount of product. Strictly speaking, the fleet size required is greater than that calculated based on demand – additional vehicles are also required to allow for vehicle maintenance, breakdowns, and licence inspections. The number of additional vehicles is usually specified as a percentage of the total fleet size. On this basis, an estimate of the actual number of vehicles in the fleet can easily be determined but the cost of holding these vehicles must be taken as included in the total operating cost of the vehicles used. This is a rather rough estimate, the cost being disproportionately higher for a small operator as opposed to a large one, but the most practical to implement.

When first looking at the resource allocation problem, one may perceive the available fleet as a fixed constraint rather than as a goal. This is a weak assumption however, providing that the fixed and variable cost of the vehicles is correctly determined. (The decision support system database includes a model for determining these costs.) When this is the case, the total operating cost reflects the total cost of the vehicle including depreciation and the cost of capital. These latter, relevant to vehicle replacement, are thus taken into account by the goal-programme when performing the assignment. Of course, there may be problems acquiring additional or different vehicles in the short term. This is allowed for in the model by imposing a constraint that can be switched on or off. However, whilst if in the short term there is a limitation on the fleet, we also need to identify the ideal fleet given the current or expected demand situation. Implementing the fleet limitations as a goal rather than as a constraint allows us to plan for the longer term. The model can thus be used to identify those elements of the fleet that should be got rid of and those vehicles on the market that should be bought in.

In terms of the vehicle availability, we set the following goal:

> The sum of the vehicles of each type across all routes should be less than or equal to the number of vehicles of each type available or acquiring additional vehicles must improve the system performance.

This can be written as:

For each period P, route R and vehicle type V:

$$\Sigma_v \text{Vehs}(R,P,V) + \text{Stocku}(P,V) - \text{Stocko}(P,V) = \text{Stock}(V);$$

Where:

Vehs(R,P,V) = Number of vehicles of type V required on route R during period P.
Stock(V) = total number of type V vehicles available
Stocku(P,V) = Number of vehicles of type V not used during period P.
Stocko(P,V) = Number of vehicles of type V, during period P, required over the available stock.

In the objective function, the under-utilisation of the fleet, Stocku(P,V), is not normally required. In the case where an employment factor is included in the design however, then this may offer the planner a mechanism for increasing the number of staff required although a “staff per vehicle” attribute would be a better measure. In South Africa, where a desire to promote the taxi industry exists, the use of the Stocku(P,V) will also tend to drive the solution towards the use of smaller vehicles. This is in line with the South African Governments policy of assisting the previously disadvantaged to participate meaningfully in the land passenger transport system. In this respect, a constraint reflecting the minimum number of some types of vehicle could also be employed.

The number of additional vehicles required, Stocko(P,V), is included in the objective function so that the planner can limit the tendency of the model to select a fleet of vehicles held by vehicle suppliers instead of by operators. As mentioned above, this deviational variable may have a zero weight for some design cases, especially long-term planning where vehicle replacement becomes an important factor.

Having developed the goal statement for the use of the available fleet, it is necessary to link the vehicle requirements to the route design. Firstly, we note that only whole vehicles can be used. The simplest way of ensuring this is simply to set the number of vehicles of each type on each route Vehs(R,P,V) as integer values. This done, the number of vehicles required depends on the minimum practical cycle time on the route and the number of vehicle trips required to meet the demand. The equation relating the vehicle trips to the vehicles is as follows:

For each period R, route R and vehicle type V:

$$\Sigma_v \left(\mathrm{Trips}(R,P,V) * \mathrm{CycTm}(R,P) / 60\right) < \mathrm{Vehs}(R,P,V)$$

Where:

CycTm(R,P) = The minimum practical cycle time on the route during period P. The value may be different for the same route during different periods due primarily to the interaction with other traffic. The cycle time is derived from the Emme/2 network model travel time and subsequent modification in the database where terminal times and allowance for boarding and alighting are incorporated. This number should ideally be an integer divisor of 60; i.e. 4, 5, 6, 7.5, 10, 12, 15 etc. This is a requirement that it is difficult to implement in the goal program. In this respect, it is only a few levels of frequency which produce unsatisfactory headways from the point of view of time tables, namely 7, 8 and 9 vehicles per hour. For the rest, the headway is either an easy enough number to remember or so short as to be irrelevant to the customers. No attempt is thus made to achieve this result. If found necessary, the planner can modify the allocation manually to achieve the desired result.

This formulation apparently implies that any number of vehicles, greater than that providing the desired number of trips, is acceptable. However, the route operating cost is affected by each additional vehicle and this limits the number of vehicles to the smallest possible value meeting the above requirement.

As mentioned previously, in the short term it may be necessary to restrict the total number of vehicles used to the available stock. In order to include this requirement in the model, the following constraint is included:

For each period P and vehicle type V:

$$\Sigma_R \text{EnfStock} * \text{Vehs}(R,P,V) < \text{Stock}(V)$$

Where:

EnfStock = A 0/1 variable, declared in the database as a true or false value. When the vehicle availability is an absolute constraint, then EnfStock = 1, otherwise it is set to zero and the constraint has no impact on the resource allocation.

Earlier, the question of selecting the fleet to best cater for all operating periods was raised. In the short term, we would like to minimise the difference in the number of vehicles of each type required from one operating period to the next. By doing this, we will maximise the utilisation of the vehicles and thus improve the distribution of the fixed cost. We will also provide some degree of standardisation of the fleet. In the long-term, knowing that there will be changes in conditions, we can set the different periods to represent one week in each of a number of consecutive years. The number of years may be the contract period for the public transport contractors. Using this approach, we can select the vehicle allocation that best suits the changing conditions rather than just the current conditions. This will limit the number of changes required to the fleet makeup over a number of years. To implement this minimisation, we need to determine the difference in vehicle numbers between operating periods. In Lingo format:

```
@For(TempStock(P,V) | P #LT# NoPeriods #AND# NoPeriods #GT# 1:
        @Sum(TempStock(I,V)|I #EQ# P+1:
                NVehs(P,V)- NVehs(I,V)) + VDiffu(P,V) - VDiffo(P,V) = 0);
```

Where:

| P #LT# NoPeriods #AND# NoPeriods s P whose index is from one to the number of periods – 1 and only when there is more than one operating period in the allocation perio

| I #EQ# P+1 ≈ For periods I whose inde iat of period P.

For example: If there are three periods, AM, I difference in the n umber of buses say, between AM and DY and DY and l. The absolute val ue of the difference is given by (Vdiffo + Vdiffu.)

Rather than trying to minimise the differe type and period pair, the maximum difference is minimised. This is f goal programmin g and is achieved by adding the additional constraint:

For each period P and vehicle type V:

Σ)VDiffu(P,V) + VDiffo(P,V)) < Max

The term MaxDiff is then minimised by incl e function. The fu ll model formulation results in this statement only bei is more than one operating period in the allocation period.

Once the utilisation is maximised, it is still n the distribution of the fixed costs over the working hours of each vehic done within Lingo , but by calculating the total hours worked in each d age working hours for each vehicle can be estimated in the database. T ked can be us sed to re-estimate the vehicle operating costs. Fortuna ehicle, the higher th e hourly operating cost is likely to be and thus the les comes. The model will thus tend to converge, possibly eliminating certain the desired allocat ion when there are adequate resources to meet all goals

The determination of the average hours work hicle requires the k nowledge of the total number of vehicle hours worked design period and also the number of each type for each operating period

$$\Sigma_{RP}\ Vehs(R,P,V) * TLength(P) = TVehHrs(V)$$

And:

$$\Sigma_{RP}\ Vehs(R,P,V) = NVehs(P,V)$$

Where:

TLength(P) = length of period P.
TVehHrs(V) = total vehicle hours for vehicle type V.
NVehs(P,V) = number of vehicles of type V operating during period P.

The average hours worked in the design period for each vehicle type is then determined as:

$$\text{Average hours worked } (V) = TVehHrs(V) / Max_P (Nvehs(P,V)$$

6.5.4 Revenue and expenses

Ultimately, the provision of public transport is subject to financial viability. How this viability is measured depends on the perspective from which the matter is viewed. Obviously, the operator expects to make a profit from his business. The local authority on the other hand, is happy if the public transport system operates to the desired levels of performance within the budgeted tax allocation. Passengers would of course like to see a suitable level of customer service, which includes reasonable fares. Irrespective of the perspective, cost is an important element in the allocation of resources to the public transport system. As mentioned earlier, quite aside from the purely monetary aspect of the cost of operating a particular vehicle, other factors are often inherent in the costing. For example:

- Local versus imported vehicles. (Import duty should favour locally manufactured vehicles.)
- Energy consumption. (The total cost of energy per passenger kilometre should be reflected in the variable operating cost.)
- Fuel type. (A preference on the part of the authorities for a particular fuel type should be reflected in the fuel price via the tax component.)

The cost element of the model is also that element most likely to need modification to suit the contractual arrangements of each project. For the purpose of demonstration and of providing a basis for an initial system design, cost is taken into account in this goal-program as follows:

The total cost of operating each route, assuming that vehicles are charged out for the full period, for any part of a period operated, is determined as:

For each period P and route R:

$$\Sigma_V \text{Trips}(R,P,V) * \text{KmCost}(V) * \text{Length}(R,P)$$
$$+ \text{Vehs}(R,P,V) * \text{PCost}(P) * \text{HrCost}(V) * \text{TLength}(P)) = \text{RouteCost}(R,P));$$

Where:

RouteCost(R,P) = the cost of operating the route for the operating period.
KmCost(V) = the cost per kilometre, the variable operating cost, for vehicle type V.
PCost(P) = the hourly cost factor or the period P. (To allow for higher night or weekend wages.)
HrCost(V) = the cost per hour, the fixed cost, for vehicle type V.
Length(R,P) = the two-way length of the route in Km.
TLength(P) = the length of the operating period in hours.

This assumes that, when one or more vehicles operate beyond the end of the period to finish the last cycle, a vehicle also started later in the period. This will allow for staggered start times or rest periods for the drivers and so is not charged as an extra operating time. Altering the period length to one hour might appear to produce the total hourly cost for operating each route but might also produce a different solution to that using the full operating periods. This is because long low-demand periods may tend to drive the overall system design towards more, smaller vehicles with lower total operating costs, lowering the overall system cost. This in turn may increase the cost of operating the peak periods when the cost per seat kilometre is higher, due to the use of small vehicles, than it would be for the larger vehicles, unsuited to low demand work.

Where vehicles are only charged for the time actually in use, this can be changed to:
For each route R:

$$\text{RouteCost}(R,P) = \Sigma_V (\text{Trips}(R,P,V) * (\text{KmCost}(V) * \text{Length}(R,P)$$
$$+ \text{CycTm}(R,P) * \text{PCost}(P) * \text{HrCost}(V)))$$

Associated with the cost on each route is the total system operating cost given by:

$$\text{TotalCost} = \Sigma_R \text{PFreq}(P) * \text{RouteCost}(R,P)$$

Where:

PFreq(P) = the number of times in the design period that the operating period occurs.

The total cost is offset by the total fare revenue. The fare revenue depends primarily on the passenger kilometres travelled. This is something of a problem as the passenger kilometres travelled in the period are not necessarily the same as those travelled in the design hour as determined by the route extraction program.

In the route extraction process, we determined the expected design-hour passenger-kilometres but we do not know the precise relationship between the peak load section and the passenger-kilometres. Consequently, when the resource allocation implies that not all demand cen be satisfied, the calculation of route revenue assumes that the actual revenue is in the same proportion to the total possible revenue as the capacity is to the peak segment demand. This is not necessarily the case but provides a conservative estimate for three reasons. Firstly, every customer not carried is assumed to have been travelling the full route length although this is unlikely. Secondly, the failure to meet demand is assumed to occur over the entire operating period although the peak demand may only occur in one hour and no passengers may be lost in the other hours. For that matter, passengers may adjust their travel time to a less congested period and the revenue is thus not lost at all. Thirdly, the failure to meet demand is measured in terms of the design capacity, not the total capacity and fewer trips are thus actually lost than are counted in the revenue calculation. The route revenue is estimated as:

For each period P and route R:

$$\text{Revenue}(R,P) = \text{Fare}(R) * \text{ho}(P) * \text{PFreq}(P) * (\text{PassKm}(R,P) * 1000 - \text{Length}(R,P) * \text{Demandu}(R) / 2)$$

Where:

ho(P) = ratio of total / peak period demand.

Length(R,P) = two way route length, hence the factor of two. This assumes that the route is the same length in each direction. The factor of one thousand comes from the fact that the passenger kilometres are measured in thousands.

(Strictly speaking, the shortfall between total capacity and demand should be used, rather than Demandu(R). It is however, then necessary to limit the latter part of the equation to the case where demand is greater than total capacity. This introduces a non-linearity.)

In order for this to work in the model, the variable Revenue(R,P) must be allowed to take on negative values. The generation of a negative value, whilst not having a real meaning and only occurring in extreme cases, can possibly be interpreted as the loss of goodwill through not providing a desired product. It arises out of the conservative assumption that a trip not carried is one that would have travelled the full route length. When no service is provided on the route, Length * Demandu is likely to be greater than the specified PassKm, resulting in a negative revenue.

This particular equation has the effect of driving the solution process towards demand satisfaction in a profit-making situation because the model maximises "profit" through minimising net cost, which can also take on a negative value.

The total system revenue is then:

$$\text{TotRevenue} = \Sigma_R \text{PFreq(P)} * \text{Revenue(R,P)}$$

In the objective function, we are interested in minimising the net cost of operating the system over the design period. The net cost is estimated as:

$$\text{NetCost} * \textbf{Mcost} = (\text{TotalCost} - \text{TotRevenue})$$

Where:

MCost = a factor to reduce the monetary value scaled units – thousands or millions, etc.

The NetCost value can be positive or negative. A positive value represents the subsidy required while a negative value represents a profit.

Because public transport systems are often not self-sustaining but require subsidisation, it is necessary to include a mechanism to limit the maximum value of the subsidy if necessary. To do this, we place an optional constraint on the maximum value of the NetCost:

$$\text{EnfSubs} * \text{NetCost} \leq \text{MaxSub}$$

Where: **EnfSubs** = a 0/1 variable used as a switch to enforce subsidy limit if desired.

MaxSub = the maximum subsidy amount for the design period.

These values are entered by the user when entering the goal weights for the objective function.

The MaxSub value is a matter for serious consideration within the strategic logistics management process. As mentioned in an earlier chapter, the public transport system has a number of functions such as:

- Providing transport for those without alternative.
- Improved efficiency of existing transport resources.
- Transport in emergencies.

The value of the maximum subsidy for each resource allocation period, and thus operating period, must be determined in light of these and other factors. For example, the authority may wish to subsidise commuters more than off-peak travellers but alternatively, they may wish to subsidise everyone equally. There may be a wish to subsidise shorter trips rather than longer ones, and so on. The planner will thus have to carry out an analysis for each period to determine the subsidy allocation for that period. It is likely that the planner will use the number of passenger-kilometres travelled in each operating period to determine the subsidy allocation. The total passenger-kilometres for the design period are given or can be determined; depending on the demand matrices used in the network model, from the Route Extraction results.

A detailed discussion of subsidy determination is beyond the scope of this dissertation but subsidy must nevertheless be borne in mind by the planner when setting the value of MaxSub. The arbitrary setting of too low a value may one-day cost the community far more than is saved now although this is difficult to sell to the local tax payers and voters.

The net cost is minimised which has the effect of maximising "profit" when it is possible to achieve one. Ultimately, minimising cost will allow the reduction of fares or the improvement of other aspects of the system at a given level of profit. Since a profit component is built into the vehicle operating costs, a profit of zero may be acceptable. There are however, costs associated with fixed infrastructure and it might be desirable to achieve a profit matching these costs before improving the service levels.

6.5.5 Number of vehicle types allowed on a route

One of the things, which it is often desirable to do, is to limit the number of types of vehicle allocated to a route. Using different vehicle sizes may enable better overall vehicle utilisation and also offer customers a choice between say bus and minibus according to their preference and the relative frequency of the different vehicle types. It is quite feasible however, for one of each of every type of vehicle to be allocated to a route during a single period. This is usually quite unsatisfactory from both the operational and the customer points of view. The model thus includes a set of statements to control this. The first of these statements are used to test whether or not a vehicle type is used:

If Trips(R,P,V) > 0 or Vehs(R,P,V) > 0 then X(R,P,V) = 1 else X(R,P,V) = 0.

These requirements can be written linear as statements in Lingo as follows:

For each period P and route R and vehicle type V:

$$\text{Trips}(R,P,V) - \text{TVB}(R,P,V) * X(R,P,V) \leq 0$$

$$\text{Vehs}(R,P,V) - \text{VVB}(R,P,V) * X(R,P,V) \leq 0$$

Where : **TVB(R,P,V)** = Maximum number of trips of vehicle type V required to meet demand on route R during period P.

VVB(R,P,V) = Maximum number of vehicles of type V required to meet demand on route R during period P.

X(R,P,V) = 0/1 variable equal to 1 if vehicle type V is used on route R during period P, else equals 0.

If even one trip is made by a vehicle type, then X(R,P,V) must be greater than zero for the inequalities to hold. Using both vehicles and trips eliminates the problem, arising in Lingo, of Vehs(R,P,V) > 0 when Trips(R,P,V) = 0.

To force X(R,P,V) to zero, we use the statements:

For each period P and route R and vehicle type V:

$$X(R,P,V) - \text{Trips}(R,P,V) \leq 0$$

$$X(R,P,V) - \text{Vehs}(R,P,V) \leq 0$$

In this case, if no trips are made, then X(R,P,V) = 0 for the inequalities to hold.

In addition to controlling the number of vehicle types allowed on a route, these statements are required for the implementation of a number of other modelling options, such as excluding certain vehicles from certain routes.

In order to limit the maximum, or minimum, number of vehicle types allowed, the following goal statement can be used:

$$\Sigma_V\, X(R,P,V) + \text{Typesu}(R,P) - \text{Typeso}(R,P) = \text{Types}(R,P)$$

Where:

X(R,P,V) = 0/1 variable equal to 1 if vehicle type V is used on route R during period P, else equals 0.

Types(R,P) = Number of vehicle types allowed or required.

Typesu(R,P) = the number of vehicle types under the desired target for route R during period P.

Typeso(R,P) = the number of vehicle types over the desired target for route R during period P.

The deviational variables Typesu(R,P) and Typeso(R,P) are then included in the objective function with weights according to the decision maker's objectives. The model is structured in such a way that these statements only come into play when the desired number of modes is less than the number of modes available or when some minimum number of vehicle types is required.

6.5.6 The objective function

Once all the goals and constraints have been specified, the next step is the construction of the objective function. (Strictly speaking, the decision-maker will have constructed the objective function in form, before the model, to have an idea of the goal-statements required.) In a goal-programme, the problem is always one of minimising the deviations from the goals important to the planner. The basic objective function describing the goals and constraints already presented is given as:

[OBJECTIVE]

$$\begin{aligned}
\text{Min} = \quad & \Sigma_R \quad \text{Du} * \text{Demandu}(R,P) && + \text{Do} * \text{Demando}(R,P) \\
+ \quad & \text{Fu} * \text{Frequ}(R,P) && + \text{Fo} * \text{MinDem}(P) * \text{Freqo}(R,P) / \text{Demand}(R,P) \\
+ \quad & \text{Tu} * \text{Typesu}(R,P) && + (\text{NoModes \#GT\# Types}) * \text{To} * \text{Typeso}(R,P) \\
+ \quad & \Sigma_{PV}\ \text{Su} * \text{Stocku}(P,V) && + (1 - \text{EnfStock}) * \text{So} * \text{Stocko}(P,V) \\
+ \quad & (\text{NoPeriods \#GT\# } 1) * \text{Dv} * \text{MaxDiff} / 100 \\
+ \quad & \text{WCost} * \text{Netcost};
\end{aligned}$$

Where: **Du** = Weight of not providing a desired space.

Demandu(R,P) = Number of passengers not able to get seats on route R during period P.

Do = Weight of providing an excess seat.

Demando(R,P) = Number of excess seats provided on maximum demand section on route R during operating period P.

Demand(R,P) = Peak section demand on route R during period P.

Fu = Weight of not meeting policy frequency.

Frequ(R) = Number of vehicle trips less than the policy frequency on route R during period P.

Fo = Weight of exceeding the policy frequency.

Freqo(R) = Number of vehicle trips over the policy frequency on route R during period P.

MinDem(P) = The minimum peak demand of all the routes operated during period P.

Tu = Weight of not having as many vehicle types as specified operating on a route.

Typesu(R,P) = Number of vehicle types less than the target operating on a route.

To = Weight of having more vehicle types than specified operating on a route.

Typeso(R,P) = Number of vehicle types over the target number operating on a route.

Su = Weight of not using all the vehicles in the available fleet.

Stocku(V) = The number of vehicles of type V not used during period P.

So = Weight of having to acquire an additional vehicle of type V in order to satisfy other goals.

Stocko(V) = The number of additional vehicles of type V required to achieve the optimal allocation of resources.

Stock(V) = The number of vehicles of type V available.

Dv = Weight of balancing the number of vehicles of each type across all operating periods.

MaxDiff = The maximum difference in the number of vehicles between one period and the next. The difference is determined for each vehicle type and the maximum of these differences is taken.

WCost	= Weight of the cost element in the model
Netcost	= The net cost of operating the system. The value will be measured in suitable units because of the MCost factor used in the cost and revenue calculations.
(1 - EnfStock)	If the stock limit is enforced, then Stocko cannot be non-zero as a result of the associated constraint: Σ_R EnfStock * Vehs(R,P,V) < Stock(V)
(NoModes #GT# Types)	We are normally only interested in the problem of too many types. Typeso is only relevant if there are more vehicle types available than are allowed on a route.
(NoPeriods #GT# 1)	Maxdiff only has meaning when there is more than one period.

It was stated earlier that many of the elements of the objective function shown above need not be included, over-supply of capacity for example. This is true, but to allow the planner the flexibility to test various conditions, all deviational variables are included in the objective function. The weights are set at zero for those elements of no consequence in the design.

In this model, the weights associated with over or under-achievement of the goal target values are applicable irrespective of period, route, mode, or line. This is not a general requirement and weights could be given for each route or mode as applicable. This would however require some minor modifications to the model and database and would result in considerable extra work for the planner. The advantage would be the ability to control the design of the routes more closely. For example, some routes may be more important in terms of meeting peak-section, peak-hour demand than others.

The objective function is self explanatory with the exception of the Freqo(R,P) and MaxDiff terms. Normally, over-achievement of policy frequency is not important. When however, there is a reason for limiting the frequency, perhaps for reasons of co-ordinated arrivals and departures, then one seeks to encourage excess frequency on high, rather than low demand routes. The higher the demand, the lower the weight of over achieving the desired frequency and the lowest demand route will have the highest weight, which cannot exceed one. This serves two purposes: Firstly, the chances are that the high demand route will be associated with a number of feeder routes. The additional frequency can be more easily spread amongst the feeders in co-ordinating routes. Secondly, the maximum possible number of passengers will benefit from the increased frequency. The frequency goal can be modelled, as mentioned previously, in a number of different ways. The Freqo term or both the Frequ and Freqo terms could be replaced with a single term minimising the maximum deviation from the target value. In either of these cases, a normalising factor is required. This is best derived from the technical limit on frequency on the network

The minimisation of the maximum difference in the number of each type of vehicle between periods has no specific normalisation factor. It is however, possible for the difference to become quite significant, perhaps running into hundreds of vehicles. The most suitable normalisation value would be the total number vehicles operating in the busiest period. The maximum difference could never exceed this number. Unfortunately, this introduces a non-linearity into the model and thus a fixed value of 100 is used to control the impact of the differences on the objective value. It is a large system that has a difference of 1000 vehicles of one type between one period and another. In this case, the objective value of the MaxDiff term would be 10 with a weight of one. In a system of this size, other factors are likely to drive the total objective value to a magnitude that will not be unduly influenced by the MaxDiff term. Manipulating the weight within the range of 0 to 10 will cover a wide range of problems.

The objective function may be considerably expanded to include many other objectives, such as those discussed in the following section. The planner is advised however, to start with the most basic model and to evaluate the solution before adding additional goals. If there are clearly spare resources, then additional goals may enhance the solution. This is however rarely the case.

The objective value has little meaning in itself although some information is available from it, subject to correct scaling, which needs to be checked for each modelling project. Since only the NetCost element can have a negative value, if the objective value is negative, we can be sure that the system is operating at a profit. It is also probable that most goals, if not all, have been met or nearly met. The magnitude of the objective function can also be interpreted to some extent. If it is significantly positive, then it is probable that demand is not met on one or more routes. If it is some small positive number, then it is likely that the total capacity will satisfy the demand on all routes but that some other goals, such as service frequency, have not been met on all routes and that a subsidy is required. The interpretation of large and small numbers will have to be determined for each project and scaling.

6.5.7 Additional options

There are many additional goals that the public-transport-system planners might wish to achieve. Some are important in particular cases; vehicle dimensions in particular can be an issue. Others are not worth adding to the model for the simple reason that their weight as compared to the other goals will nullify their impact on the model. However, the planner may wish to experiment with particular additional goals when resources allow. A few examples are given below.

6.5.7.1 Pollution and Energy targets

The planner may specifically wish to include some degree of pollution control in the model. This is relatively simple to implement and introduces no non-linearity. Essentially, the cost determination equation is modified to reflect the particular pollutant(s) under consideration instead of the KmCost and HrCost values. One equation is added for each pollutant. The total "PollutantCost" is then minimised as an element of the objective function.

:

For each period P and route R:

$$\Sigma_V \text{Trips}(R,P,V) * \text{Pollutant\_Km}(V) * \text{Length}(R,P)$$
$$+ \text{Vehs}(R,P,V) * \text{Pollutant\_Hr}(V) * \text{TLength}(P)) = \text{PollutantCost}(R,P));$$

An exactly equivalent goal statement can be constructed with the energy consumption values. To maintain linearity in the model, average values will have to be used rather than accurate, speed dependent functions but this will nevertheless give the planner a reasonable set of guidelines, if not the ultimate solution. The data for each type of vehicle must be appended to the database and the goal programme model must be modified to retrieve the necessary data.

6.5.7.2 Employment opportunities

In South Africa, a major concern is the high rate of unemployment. The public transport planning authority may wish to promote high employment modes. If some rate of employment per vehicle can be established – for example, a single taxi may support two point three people whereas a bus may support four people – then this can be added to the model as follows:

$$\text{TotalEmployment} = \Sigma_{RV} \text{Vehs}(R,P,V) * \text{Employment rate}$$

The TotalEmployment variable is now subtracted from the objective function with a suitable weight and normalisation factor. The normalisation factor must be a constant and so the total number of vehicles used on the system cannot be used. Some experimentation may be required to determine a satisfactory value.

6.5.7.3 Vehicle limitations on certain routes

There may be certain routes for which there are structural limitations on the vehicles that may use them; for example vehicle height, weight, or length. If these routes can be identified, and a value assigned to them in the database indicating the restriction value, then a constraint or goal statement can be added to the model preventing certain vehicle types operating on certain routes. Vehicle height, length, and weight restrictions can be introduced as follows:

$$X(R,P,V) * VehHeight(V) - MaxHeight(R,P) \le 0$$

$$X(R,P,V) * VehLength(V) - MaxLength(R,P) \le 0$$

$$X(R,P,V) * VehWeight(V) - MaxWeight(R,P) \le 0$$

For the purpose of demonstration, the first two constraints have been included in the working model. Care must be taken in formulating these statements in Lingo if the model is not to generate constraints in which, for example, the **sum** of the vehicle type property across all vehicle types must be less than the route maximum. The proper Lingo formulation is shown in APPENDIX L. The full formulation results in constraints being generated only when there is a possible problem; i.e. when a particular vehicle has a dimension exceeding the route limit.

The same technique can be used in the allocation of specific vehicle types to routes meeting certain criteria. For example, buses with on-board catering facilities to long routes, or limited seat buses to short routes. Usually, the essential factor on the route will be the route length or travel time. An associated attribute will have to be declared for each vehicle type, so for example, we might get a goal statement of the form:

$$X(R,P,V)*MinRouteLength(V) + Short(R,P) - Long(R,P) = Length(R,P)/2$$

This particular requirement must be presented as a goal and not a constraint since otherwise, it might be impossible to satisfy the demand although the vehicle capacity exists and many vehicles are unutilised. In the luxury vehicle case, the deviational variable, Short(R,P) will be minimised, while in the limited seat vehicles, Long(R,P) will be relevant. (The deviational variables must have different names for the different requirements.) A similar structure can be used to promote the use of certain classes of vehicle on certain types of route based on cost. For example, where a high capacity, basic service is provided to low-income users at some nominal fare.

One of the common criteria of pavement design and road maintenance is the loading of the pavement measured in E80's – equivalent 80kN axle loads. If on some routes it is desirable to minimise the loading resulting from the use of heavy public-transport vehicles then this could be added as a goal or constraint in the model. By adding the E80 loading of each vehicle type to the vehicle attributes, one could restrict or limit the loading on particular routes by means of a simple additional constraint of the form:

For each period P and route R:

$$\Sigma_V \text{Trips}(R,P,V) * \text{E80s}(V) \leq \text{E80Limit}(R,P)$$

This constraint could naturally be converted to a goal statement instead if desired. Because public transport vehicles form a relatively small proportion of the total number of heavy vehicles using most sections of road, there is little purpose in taking this evaluation much further. It is however, worth noting that there is a cost trade-off involved here. If one limits the maximum vehicle weight, then it is quite likely that the cost of the public transport operation will increase. Strictly speaking, this must be offset against the saving in road maintenance due to the reduced loading. Converting the above constraint to a goal statement, the underachievement deviational variable can be used, with a suitable multiplier, to represent the cost saving in the transport system. This saving, or part of it, can be reflected as reduction in the net cost of the public transport system.

6.5.7.4 Willingness to pay for improved levels of service

Although Prioni and Hensher (1999) suggest that the effect is limited, there is a possibility that customers will be willing to pay higher fare for improved service frequency or better vehicle quality. That this is, or is not, the case needs to be determined by means of stated and revealed preference studies for each public transport region. If a significant willingness to pay for improved service is found to exist, the planner may be able to include some facets of this in the model.

This could be achieved in the case of service frequency by developing an equation relating the fare to the service frequency and then using this in the determination of route revenue:

$$\text{Fare}(R,P) = f(\text{Trips}(R,P))$$

The revenue statement would be modified to reflect the fare as a function of the number of vehicle trips. Unless all demand is known to be satisfied and the Demandu term can be dropped from the revenue calculation, this will introduce a non-linearity into the model, even if the function is linear. Thus, this should only be introduced into a linear model when resources are clearly adequate, the demand requirements can be restated as constraints, and the function relating the frequency and the fare is linear.

When resources are not in abundance, a more stable way of achieving a similar result is to increase the policy frequency and fare, in the database, on those routes where the willingness to pay is known to exist. The planner may nevertheless wish to experiment with the non-linear approach, software allowing.

6.5.8 Weighting the deviational variables in the objective function

In discussing Equation 6-8, it was stated that the objective function required normalisation to ensure that the relevance of deviational-variables of different magnitude did not distort the priority or weight placed by the decision-maker on the goals. In the subsequent formulation however, the normalisation factor has not been included. This is because, with the exception of the cost and total vehicle number terms, the units of deviation are relatively comparable, being measured in person or vehicle trips, or vehicles. (When the deviational variables reach proportions that place them out of balance with the others, there is a far more serious capacity problem than can be resolved by the model.) This is fortunate because the normalisation process recommended by Romero (1991) results in the objective function being measured in per unit values. The question then arises as to the relative value of 10% of 1000 passengers and 10% of a policy frequency of 10 vehicles per hour. Without normalisation, it is easy to see the relationship between the deviational variables and to make considered decisions based on their values.

The cost function requires normalisation to reduce the order of magnitude of the net cost element to units. (For example, if the net cost is measured in millions then the multiplier should be 1×10^{-6}.) This has to be determined by running the model with an estimated value, which can then be refined preceding a second iteration. The model will remain stable without this multiplier but will give answers biased too much in favour of cost, not necessarily reflecting the decision-maker's priorities. With the multiplier, the net cost also has units comparable with the deviational variables.

The model is best run with important goals initially having a weight of one and the unimportant ones having a weight of zero. The constraint-versus-goal switches are set off. Weights that are more accurate can be set using the solution of this model should the result not reflect the goals of the decision-maker already.

This may seem somewhat naïve an approach to the problem of resource allocation, but is based on the properties of the model. There is a relationship between the deviational variables, which tends to create a natural set of priorities that are, in the authors opinion at least, correct.
In the basic model, these priorities are:

1. Meet the demand.
2. Achieve the desired service frequency.
3. Do not use vehicles not in stock.
4. Keep the costs to a minimum.

The reason that this priority exists when all the weights are set to one can be understood as follows:

To start with, it can be seen that one person trip is equivalent in the objective function to one vehicle trip or one vehicle or one unit of cost, assuming that the cost element has been correctly scaled. If only one person cannot get a seat or alternatively, one vehicle trip must be eliminated, the cost element will tend to pick the best monetary solution. Given the fare revenue and vehicle operating costs involved, the cost element involved in the decision will be small compared with the other factors.

Key to the whole issue is that if demand is just met by a certain number of vehicle trips, then the failure of one vehicle trip results in under-supply on the route equal to the vehicle capacity. Failure of a vehicle, as opposed to a vehicle trip, may mean the loss of several vehicle trips and thus more passenger-trips. Thus, whenever there is a shortfall of either vehicle trips or vehicles in meeting the demand, the impact of the unsatisfied customers is usually much bigger in numeric terms than the number of vehicle trips or vehicles involved. On occasion however, the solution to the goal programme model implies that a number of passengers are not being catered for and yet all the routes meet their frequency target. This occurs when for example; only one vehicle is needed to satisfy all goals on one route, and on a second route, the unsatisfied demand is less than the total demand of the first route. Transferring the vehicle from the first to the second route will make the situation worse although at first it may appear that frequency has been satisfied before demand.

When the demand is easily met with the available fleet but other goals are not necessarily achieved, the issues are not quite so clear. There is an element of double counting of most of the deviational variables, the demand inasmuch as that the cost function includes the fare revenue. Thus, failing to provide for the passenger imposes a penalty in the Demandu(R,P) deviational variable and in the net cost variable through lost revenue. The frequency however, works in reverse. Excess frequency with respect to demand requirements costs money and so underachievement of the desired level of frequency may result in reduced net cost. The solution will thus depend on the scaling of the monetary terms, (thousands, millions etc.,) the fare revenue, and the vehicle operating costs.

Fleet utilisation, (Stocko(R,P), tends to be less important in the solution than frequency at the same weight because often, one additional vehicle will result in more than one vehicle trip. I.e. a shortfall in frequency of two or three vehicles per hour may be resolved by the addition of one vehicle to the fleet. In this case, again, the deciding factor when there is a one on one choice between stock utilisation and frequency, is the cost element.

Finally, the cost is less important than the other factors because the change in income or expenditure arising from any of the other goals is divided by the factor converting the net cost into units. Thus, if an additional vehicle raises costs by R 300 per hour and the system cost is measured in millions, then the impact of the additional vehicle is of the order of 3×10^{-4}. The result is that the cost function, whilst always present, plays only a background role in the decision making process providing the multiplier is of the right order. In order to counter this, making the subsidy a constraint prevents the cost being overrun in favour of other goals.

The result of this "natural" prioritisation is that weights of zero or one serve to generate a sensible solution similar to the result one might expect from a lexicographic model. (See Section 6.2 and Equation 6-5.) Keeping in mind the relationship between the deviational variables, it can be seen that the weights will need to reflect the number of passengers who are left without service when raising the priority of other goals above that of satisfying demand.

For example: Consider a route with a height restriction precluding the use of standard buses and with a peak demand of 60 passengers. If the policy frequency is 2 vehicles per hour, then we will normally exceed the policy frequency by 3 vehicles per hour in order to meet the demand. In order to ensure that the frequency does not exceed the policy frequency, we need a weight >12.6 for the Freqo term in the objective function. This is determined by noting that the design capacity of the only vehicle able to operate on the route, because of the height restriction, is 12.6 passengers. Each vehicle trip over the policy frequency is thus worth 12.6 passengers. Had a bus been a viable option, demand would have been met with two vehicle trips. The difference in cost between the two vehicles would have been of less magnitude in the objective function than the frequency deviation. A weight of one would thus have produced the desired result, other factors being satisfactory.

6.6 RUNNING THE MODEL

There are some strictly practical issues to be considered in using the goal-programme model:

Solving mixed integer problems (MIPs) is usually considerably more difficult than solving non-integer problems. When allocating resources in a large system it is thus worthwhile running the model as a non-integer (LP) problem by eliminating the integer constraints on the relevant variables. Even a large model may then be solved in a matter of seconds. This allows the planner to ascertain that the model can be solved at this level and tests the data. As many variable bounds as possible are determined in the DSS and applied in the GP model. The LP results may however, allow these bounds to be further tightened, thus improving the solution time of the MIP. If for example, all demand is met and there are vehicles not used, then it is reasonably safe to set the upper bound on the under-achievement of demand at zero. The lower bound on the service frequency can possibly be increased and other boundary values can be set, including those on net cost and total cost. It is worth spending some time on this as the problem may be solved in a minute or less once judicious bounds are set, as opposed to several hours if the bounds are too broad.

A useful result of this approach is that it gives the planner some useful information regarding the minimum costs of providing a service on any route and for the system. The values determined will, in general, be impossible to achieve; they do however provide a lower boundary value, especially when considering tenders. A price below the boundary value is unlikely to be correctly determined and acceptance of such a tender is almost certainly going to lead to difficulty during the course of the contract.

When solving the integer problem, a good estimate of the optimal objective value may be determined from the non-integer solution and set as a hurdle value[3]. Setting the hurdle value is however, really a matter of trial and error. The solution branch on which this hurdle value is to be found is usually found relatively promptly by the solver. Thus, a series of increasingly less or more demanding hurdles can be set and the integer problem submitted to the solver each time. If after a few minutes, the solution remains infeasible, the hurdle value is too constrictive and must be eased. To do this, the process is interrupted restarted with a new hurdle value. Even when a good hurdle value is found, the number of computations in reaching the solution may be enormous in the integer problem.

There is another aspect to using the model, more closely related to the strategic logistics management objective in which we seek the best design for our public transport system considering all factors. Every restriction placed on the resource allocation process may have a cost associated with it. For example, a height restriction may call for the use of small and expensive vehicles. The question must then be asked as to whether or not the reason for the restriction must be removed or the route altered to avoid the restriction. Vehicle restrictions may extend to several routes when the restriction lies in an interchange facility. If the model is run without the restriction and again with the restriction, it will be possible to estimate the cost of the restriction to the system and thus the value of modifying the system to eliminate the restriction.

The implication of the above is that the model should be run several times, first with no restrictions whatsoever and then for a fully restricted system. If there are potential improvements, these will show up as a cost difference between the two runs. The planner can then add and remove restrictions in the model to test the value of each restriction. It is important to note that whilst often, the changes will only affect a small portion of the public transport system, there may be restrictions which have an impact, direct or indirect, on the operation of the entire system. For example, not being able to accommodate a particular vehicle type in one place may lead to an inappropriately expensive vehicle being used elsewhere to satisfy fleet constraints. Consequently, the cost of a modification, not apparently justified for the part of the system actually directly influenced, may be more than justified by the impact on the entire system.

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[3] A value used to eliminate unlikely branches when searching for an initial integer solution. See LINDO Systems 1999.

It should also be noted that the restrictions might have an impact that is not measured in monetary terms. Using the vehicle restriction example again, on a per passenger-kilometre basis, the restriction may impose heavy pollution costs. Alternatively, by drawing many small vehicles onto one route, it may unduly affect the service frequency on other routes through lack of suitable vehicles. The planner should thus evaluate the results of the allocation process thoroughly with respect to restrictions.

6.7 EXAMPLE RESOURCE ALLOCATION RESULTS AND THEIR INTERPRETATION

The goal programme has been applied to the Transit example in Appendix H, to demonstrate the results and their interpretation. This example is based on **one hour of operation** only but demonstrates the function of the model as well as showing that the results are not always those expected and should be carefully evaluated before being cast aside as incorrect.

Partial results have been presented in this document in modified format. The full result printout needed for a true evaluation of the results is extensive and typically requires about six pages to present. In the last example, twelve pages are required. Consequently, the reader is referred to the accompanying CD for complete example printouts.

6.7.1 The base data

In the example, there are six routes with varying peak-section-demand, length, and minimum cycle-times. The route details as applied to the goal-programme are shown in Table 6-1.

Route:	**1**	**2**	**3**	**4**	**5**	**6**
Operating Period[1]	AM	AM	AM	AM	AM	AM
Demand	230	230	169	168	150	60
Policy Frequency	4	4	4	4	4	4
Maximum Frequency	30	30	30	30	30	30
Max. Passenger. km	1031	796	629	633	488	100
Fare	R0.60	R0.60	R0.60	R0.60	R0.60	R0.60
2-way Length (km)	10	8	8	10	8	4
Minimum cycle time (min)[2]	19	16	13.1	15.1	12.6	8
Vehicle types	2	2	2	2	2	1
Maximum vehicle length (m)	22	22	22	22	22	22
Maximum vehicle height (m)	6	6	6	6	6	6

Table 6-1: Base-scenario route details for resource allocation.

Notes to Table 6-1:

1. The operating period is assumed one hour long.

2. The minimum cycle time is the minimum travel time plus the minimum terminal time at each end of the route. The terminal times are specified in the database by the planner.

The database also has the details for two vehicles, a 14-seat minibus, and a 60 passenger standard bus. The basic details are shown in Table 6-2.

Vehicle	Taxi	Bus
Fleet size	100	100
Policy load factor	0.9	0.9
Total capacity	14	60
Cost per hour[1]	R59.00	R117.79
Cost per kilometre[1]	R0.48	R2.09
Vehicle height (m)	2.4	3.2
Vehicle length (m)	5	9

Table 6-2: Base scenario vehicle details for resource allocation.

Notes to Table 6-2:

1. The per-hour and per-kilometre costs for the vehicles are either provided directly by the planner or determined within the database from fundamental data. The determination of these costs is discussed in Chapter 7 on vehicle costing and replacement cycles.

In order to run the resource allocation model the planner must provide additional information. This information includes the total amount available for subsidisation of the system, the weights for the achievements of various goals and the switches indicating enforcement or otherwise of constraints. Most of these were specified in previous sections of this chapter but are summarised in Table 6-3 for reference.

Element	Weight, Switch or Value	Description	Value
DU	W	Under supply	1.0
DO	W	Over supply	0.0
FU	W	Under frequency	1.0
FO	W	Over frequency	0.0
TU	W	Under vehicle types	0.0
TO	W	Over vehicle types	1.0
SU	W	Under utilisation of fleet	0.0
SO	W	Over utilisation of fleet	1.0
ENFSTOCK	S	Enforce vehicle availability Y/N	0
SUBS	W	Cost	1.0
MAXSUB	V	Maximum subsidy (R)	R1000
ENFSUBS	S	Enforce subsidy Y/N	0

Table 6-3: Base-scenario control values for resource allocation.

As can be seen from a study of the data in Table 6-1,Table 6-2 and Table 6-3, the solution is unconstrained in any way. There are clearly enough vehicles, there are no physical restrictions, the route limitations exceeding the vehicle dimensions and the amount available for the subsidy, which is not enforced, is high enough. The number of vehicle types allowed is equal to the number of vehicle types available and so there is no chance of more vehicle-types being allocated to a route than specified.

6.7.2 Base-scenario allocation results

The allocation of resources given these parameters will seek to match demand and frequency within the available fleet and minimum cost. The results of this allocation are shown in Table 6-4, Table 6-5 and Table 6-6. These three tables show the relevant results in full. There are additional results in the Lingo output but these are related to the process rather than to decision making directly. The reproduction of such tables for every example discussed is considered unnecessary and only the salient points are discussed for most of the examples. For each case however, there is a Lingo Solution file on the accompanying CD. The name of the file is given in the appropriate place. For the base scenario, the file name is Transit1.lgr. This type of file can be opened with Lingo or with any text editor if Lingo is not available.

The important points to be observed in the results of the base-scenario resource allocation are that all the goals have been achieved and that the total cost of operating the system during the design hour is R 1356. This cost will be compared against that arising from other conditions.

Route	1	2	3	4	5	6
Demandu (Pass.)	0	0	0	0	0	0
Demando (Pass.)	7.6	7.6	47	6.6	1.2	3
DesCap (Pass.)	237.6	237.6	216	174	151.2	63
TotCap (Pass.)	264	264	240	194	168	70
Frequ (Veh. Trips)	0	0	0	0	0	0
Freqo (Veh. Trips)	5	5	0	0	8	1
Taxi Trips	6	2	0	0	12	5
Bus Trips	3	4	4	4	0	0
Tot. Veh. Trips	9	9	4	4	12	5
Taxis	2	2	0	1	3	1
Buses	1	1	1	1	0	0
No. Vehicles.	3	3	1	2	3	1
Typeso	0	0	0	0	0	0
Revenue	R618.6	R477.6	R377.4	R379.8	R292.8	R60.00
RouteCost	R327.05	R308.8	R184.54	R244.15	R222.89	R68.56

Table 6-4: Route based results of base-scenario resource allocation.

	Taxi	**Bus**
Stocku (Vehicles)	91	96
Stocko (Vehicles)	0	0

Table 6-5: Vehicle based results of base-scenario resource allocation.

TOTREVENUE	R2206.20
TOTALCOST	R1356.00
NETCOST	-R850.20
NOMODES	2
NOROUTES	6

Table 6-6: Network based results of base-scenario resource allocation.

This particular result is interesting in that if one drops the demand requirement, i.e. set Du to zero the same result is achieved. (See Transit2.lgr) This occurs because the frequency presents a greater weight than cost in the objective function because of the normalisation factor applied to the cost values. In this particular example, failure to provide any service at all leads to an objective value of 24 (the sum across all routes of the policy frequency) whereas in providing an adequate service, the cost never has an impact over 1,4 units in the objective function.

6.7.3 Resource allocation without the frequency goal

If now, the frequency goal is removed, i.e. Fu is set to zero, with Du equal to one, the total cost is reduced, as one would expect, to R1300.96 from the R1356.00 when the frequency goal was being met. (See Transit3.lgr) All other goals are met although the total capacity is increased on one of the routes. This occurs because it is cheaper to use high capacity buses rather than taxis to meet the demand when the minimum frequency is not met. In the example, the system is operating at a profit and the only purpose in reducing the frequency would be increased profit. This may however lead to reduced customer satisfaction and ultimately, reduced profits.

The preceding two cases demonstrate the general function of the model and the minimum cost of meeting the demand with the available resources. The cases have however been simple. In the normal course of events, other problems arise – What happens when some of these occur?

6.7.4 Insufficient fleet to meet demand

In the base-scenario, nine taxis and four buses were required to meet demand. Let us reduce the fleet size to six taxis and four buses:

If the stock is not constrained, i.e. the number of vehicles available can be increased, then the solution is the same as the unconstrained frequency solution, given that the objective function value will have changed. (See Transit4.lgr) In other words, the system should get one additional bus. The reason for this result is that it is "cheaper" to provide one less than the policy frequency and add one expensive vehicle than to meet frequency and add two expensive or three cheap vehicles to the system.

Table 6-7, Table 6-8 and Table 6-9 show the results of the constrained allocation of resources when there are insufficient vehicles; i.e. when extra vehicles may not be brought in. (See Transit5.lgr) An interesting feature of these results is that the frequency goal is achieved or exceeded on all but one route although the demand goal is not. This seems unreasonable at first glance, given the fact that the inherent priority of the demand is higher than that of the frequency. The reason that this occurs is that the number of vehicles required to best satisfy the demand on each route is such that the policy frequency can be met. Because a vehicle assigned to a route cannot transfer to another route, the vehicle is able to make up the policy frequency on its first assigned route but not to help meet demand on another route. (If in reality a vehicle can be used on more than one route, this will be preferable.)

Both revenues and costs are lower than for the base scenario. This makes sense in that some passengers have been lost from the system and fewer vehicles are being operated.

Route	**1**	**2**	**3**	**4**	**5**	**6**
Demandu (Pass.)	30.2	30.2	0	6	0	0
Demando (Pass.)	0	0	47	0	1.2	3
DesCap (Pass.)	199.8	199.8	216	162	151.2	63
TotCap (Pass.)	222	222	240	180	168	70
Frequ (Veh. Trips)	0	0	0	1	0	0
Freqo (Veh. Trips)	2	2	0	0	8	1
Taxi Trips	3	3	0	0	12	5
Bus Trips	3	3	4	3	0	0
Tot. Veh. Trips	6	6	4	3	12	5
Taxis	1	1	0	0	3	1
Buses	1	1	1	1	0	0
No. Vehicles.	2	2	1	1	3	1
Typeso	0	0	0	0	0	0
Revenue	R528.00	R405.12	R377.40	R361.8	R292.80	R60.00
RouteCost	R253.71	R238.33	R184.54	R180.37	R222.90	R68.56

Table 6-7: Route based results of base-scenario resource allocation.

Another aspect worth noting is that the total capacity provided is such that actually, only eight passengers on each of routes one and two will not be able to board the line on the peak load section. It does not work in this example, but changing the load factor of the vehicles can produce a slightly different allocation of the vehicles so that more demand can be satisfied with the available vehicles. In this particular example, the same number of trips remain unsatisfied but the costs and revenues are improved. (See Transit6.lgr.) The planner must therefore decide, when the fleet size is constrained, on whether to risk overloading elsewhere, or to know that on one route, demand will not be satisfied.

	Taxi	**Bus**
Stocku (Vehicles)	0	0
Stocko (Vehicles)	0	0

Table 6-8: Vehicle based results of base-scenario resource allocation.

TOTREVENUE	R2025.12
TOTALCOST	R1148.40
NETCOST	-R876.72
NOMODES	2
NOROUTES	6

Table 6-9: Network based results of base-scenario resource allocation.

6.7.5 Vehicle restrictions

Although not that common, instances do exist where certain vehicles cannot be used on certain routes because of some size limitation on the route, a low bridge for example. In South Africa, this might occur where facilities have been developed specifically for the min-bus taxis and some classes of larger bus, double deck buses for example, cannot be operated in those facilities.

Modifying the base-scenario data to reflect a height limitation on route three, which we see is best served by a bus leads to the result in which only taxis are assigned to this route. (See Transit7.lgr) The total cost is increased to R 1461 from a base value of R 1356 and thus the profit is reduced for the hour under evaluation. Thirteen taxis and 3 buses are used in this allocation.

If the number of taxis is limited to 8, buses to 4, and the fleet size is constrained, then the optimum allocation of resources results in the under-supply of design capacity on routes three and four although total capacity is adequate on all routes. (See Transit8.lgr) Revenue and cost are both reduced by the restriction on the fleet size. Interestingly however, the profit is better under constrained vehicle conditions than unconstrained conditions. This occurs, in this case, because the loss of revenue is less than the reduction in cost. This is not necessarily always the case but is an important reason for using the correct normalisation factor for the cost element in the objective function. Using the wrong factor can weight the model in such a way that profit comes before customer satisfaction. Even when the system is able to operate viably at the prescribed level of customer service, poorer service is offered in favour of greater profit.

6.7.6 Number of vehicle types

This example looks at the allocation of resources given a limited fleet, as before, with a height restriction on route four and only one vehicle type allowed on any route. This is done for an unconstrained and a constrained fleet.

Studying the results, given in Transit9.lgr and Transit10.lgr respectively, we see that in the unconstrained case, all goals are met except that for available vehicles, where two extra buses are required. The hourly cost is relatively high at R 1558.90 as opposed to the base-scenario value of R 1356. In the constrained case, we see that the demand goal is not met but that the total capacity is nevertheless adequate on all routes. The cost is lower than for the unconstrained case at R 1279.35. This is also less than the base-scenario case for the same reason as before, i.e. that we have not met all the objectives. This leads to two observations: Firstly, increasingly constraining the model does not necessarily result in increasing cost or a worse solution, but rather one that offers less margin for error. Secondly, often, the more constrained the model, the more quickly the optimum allocation is found, the number of feasible solutions being fewer.

These examples have dealt only with weights of zero or one and always achieved a result that is meaningful in terms of normal practice. Because of the difficulty and subjectivity of developing meaningful weights, the author believes that this a positive aspect of the model. The planner will have to decide when and where to employ more complex weightings and no specific examples are given here.

6.7.7 Multi-period allocation

So far, the examples have all been single period examples. The principle is unchanged for any number of periods. As an example of the multi-period resource allocation, the routes in the Transit model have been duplicated, the second set being the evening peak period. The one difference in the route requirements is that the policy frequency for the PM operating period is half that of the AM operating period. There are now twelve routes instead of six but the number of available vehicles remains unchanged. The example, the results of which are shown in Transit11.lgr and Transit12.lgr, differs from the earlier examples in that the operating period length (Tlength(P)) has been changed from one hour to four hours in each case and the ratio of the total to design hour passenger kilometres (ho(P)) is three. This demonstrates the effect of these values, which essentially increase the cost by four and the passenger kilometres and thus revenue by a factor of three in this particular example. The periods do not need to have the same values and in this case do so, so that the results for the different periods can be readily compared. The result is that many of the numbers, passenger-kilometres, fare revenue, and total operating costs, are significantly greater than before but the form of the result is the same.

The two result files represent the condition where the fleet is limited but not constrained and where it is limited and constrained respectively. In this last case, one deviation for each goal and all the constraints except the enforcement of the maximum subsidy are applied. Since the system operates at a profit, the subsidy is in any case not used. A detailed summary of the result output from Lingo is provided as APPENDIX I.

6.8 MODEL WEAKNESSES

It is the nature of models that they simplify reality and in the process, sometimes lose some degree of accuracy. This particular model has a number of weaknesses in this respect, which the planner must keep in mind:

6.8.1 Run-Cutting

Quite often, a vehicle required for a route completes its work on that route well before the end of the operating period. This vehicle could then be re-assigned to another route for the remainder of the period. Similarly, two or more routes having one terminal each within some relatively small region may be better served by swapping vehicles for part of the period. For example, a bus may swap with a taxi at the end of a cycle, more closely meeting the demand and possibly eliminating the need for an additional vehicle on one of the routes.

This model does not reflect such possibilities at all. This is definitely a weakness but the author does not believe that this negates the value of the model as presented. This is because the model offers a good but conservative allocation of resources and the planner thus has a basis upon which to evaluate further refinements. Furthermore, in the multi-operator environment for which the model is developed, run cutting is not very likely to occur.

6.8.2 Dead-Heading

There is always a cost associated with moving the vehicles and, or, drivers and other on-board vehicle staff between the route and the vehicle depot or staff centres. In the multi-operator environment in particular, one expects costs to be minimised by allocating operators to routes nearest to their depot. The model fails on two points: Firstly, it does not take into account the deadhead costs at all, the actual net cost will thus tend to be under-estimated in this respect. Secondly, it does not specifically assign operators to routes based on the proximity of their depot to the routes that they might serve.

The first of these problems can be eased by means of a multiplier in the cost function, associated with the hourly operating cost for each vehicle, assuming that sufficient data is available to develop such an estimate. In other words, a system wide average deadhead cost per vehicle is determined and applied to each route given its vehicle requirements. The second problem, and to some extent thus also the first, can further be dealt with through the use of a second model. In this model, the tender prices of all operators are associated with the routes upon which they tender. The optimum allocation of operator to route is then determined. This may often mean taking a tender other than the lowest on one or more routes so that the overall cost is minimised. It is also conceivable that more than one tenderer will be assigned to one route. The data arising from this model can then be used as a basis for the multiplier in the resource allocation model or as a route based deadhead cost, added to the other route operating costs.

When more than one operator is to be used on a route, tenderers can give per vehicle rates for operating on different routes and the limit on the number and type of vehicles they can supply. These rates will be the per-kilometre, per-hour, and deadhead costs for each vehicle type, for each route in which the tenderer is interested. Since the allocation of tenders depends largely on the form of the contractual arrangements, a general allocation model cannot be readily devised. A simple example of how such a model might look is however shown in APPENDIX M and the model is included on the accompanying CD.

6.8.3 Sub-Peak allocation

The demand on many routes is subject to what might be termed "sub-peaks." These occur when, for instance, the trip attraction is a centre of employment and the bulk of the jobs start and end at particular times of day. Most people try to get to work just in time and like to leave immediately the whistle blows. A few minutes before and after these times, the demand is much lower. The network design model is however, usually based on a one-hour average. If only one vehicle type is used, then bunching them at the appropriate time leads to continually changing timetables. This is undesirable. When more than one vehicle type is being used though, it may be possible to structure the schedule so that the larger vehicles arrive at and leave from the peak demand point at the peak time. The model makes no allowance for this form of scheduling which must be carried out separately by the planner.

6.8.4 Modelling language problems

Subsequent to the development of the model, it was found that Lingo is not without its problems. The resource allocation model has been tested with other software as discussed in section 9.8 and so it is known that some of the problems encountered are due to the Lingo Solver and not to the model structure. Alternative software is thus worth investigation.

The integer solver included in Lingo optionally uses a cutting-plane solution method. The "cuts" are additional constraints, based on the non-integer solution of the problem, reducing the feasible region until an integer solution is found. In Lingo, the default option is the use of "Flow Cuts" with an option of using Gomory Cuts or no cuts. These cuts are supposed to improve the solution time but have been found to sometimes give trouble when implementing the model. In particular, using the Gomory Cuts often leads to model failure or a sub-optimal solution. This appears to be due to a problem with the Lingo solver. Other solver packages may perform significantly better. Setting the Lingo solver not to use cuts eliminates this problem but may increase the solution time considerably. It is thus worth experimenting with each model. The author believes that a few extra minutes or even hours of computer time cannot be considered a burden when the improvement in the solution, as small as it might be, may produce extensive savings in the system cost. The planner should experiment with the Lingo options when no feasible solution is found. The very nature of the goal programme is such that there is almost always a feasible solution, even if it is only that of providing no public transport.

6.8.5 A note on using the model with the database

An important thing to remember is that the computerised decision support system presented here is in a relatively unpolished format intended to demonstrate principles, not as a commercial product at this stage. Consequently, many of the components are able to operate independently of the others to allow for model development and demonstration. The result of this is that functions that would be automated in a commercial model are not in this example. This can lead to apparent problems with the Lingo goal programme model, which relies on properly structured data, in turn dependent on a specific sequence of processing. When running the model in this format therefore, the user must take care to ensure that the sequence of data preparation discussed in Chapter 9 is followed.

6.9 REFERENCES

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7 FLEET COSTS

7.1 INTRODUCTION

In the last chapter, the operating costs, measured in time and distance terms, were of considerable importance in assigning vehicles to routes. These are of course, average values for each vehicle type, not vehicle or even operator specific. Many factors contribute to the total cost of operating a vehicle fleet and to the revenue earned. Amongst these, are the number of hours worked and kilometres travelled by each vehicle and the ages of the vehicles. Under certain conditions, the number of each type of vehicle being operated is also important as it may lead to significant economies of scale ranging from initial capital cost through to spare parts and maintenance staff.

In theory, some of these factors could be introduced directly into the resource allocation model. Doing so however, introduces significant complications into the goal programme, which make its solution slow and possibly unstable, given the non-linearities that arise. Fortunately, the loss on the one side is countered by a gain on the other. The separate evaluation of vehicle costs enables both authorities and operators to quickly evaluate the impact of various changes on individual vehicle costs without the complications of the full resource allocation process. This is especially the case where small operators with limited experience in vehicle costing might need guidance in tendering for the provision of services. Detailed costing will allow these operators to examine areas for cost improvement within their business and thus to improve their revenues by being more competitive when offering services.

This chapter is divided into two sections, both essentially associated with the total operating costs of the fleet vehicles. The first deals specifically with estimating the fixed and variable costs of operating a vehicle. The second deals with the more subjective question of vehicle replacement cycles and their impact on the costs and revenues of a vehicle. The chapter is intended to outline the tools provided in the decision support system (DSS) and to highlight some of the issues to be considered in determining the vehicle operating costs. The tools are provided to enable the planner to make estimates without detailed information, as may be necessary for new vehicle types or when operators are not forthcoming with information. Where accurate "real" data is available, this would be a preferable source for detailed evaluation, especially given the different characteristics of operators of vehicle types as diverse as conventional buses and mini-bus taxis.

7.1.1 Fixed and variable vehicle operating costs

Before proceeding, two basic definitions are given here to ensure clarity later. Associated with every vehicle used in a public transport system are two cost components, the fixed cost, and the variable cost. These are discussed in detail in many texts including those of Cooke (1974) and Lowe (1989) and thus only a very brief overview is given here.

7.1.1.1 Fixed costs

The fixed costs associated with a vehicle are those costs independent of the distance travelled by the vehicle. These fixed costs are further split into two components, standing, and overhead costs. Standing costs are associated specifically with the vehicle, for example, the salary of the driver, vehicle insurance, the garage space, and the cost of owning the vehicle. Overhead costs on the other hand are not specific to any vehicle. Examples are the administrative overheads of the business, such as management costs, office rental and so on, that must be shared across the fleet. In public transport, standby vehicles to accommodate breakdowns and accidents are required. Depending on how the fleet is operated, maintaining a relatively equal mileage on all vehicles of an age group for example, the fixed costs associated with standby vehicles may be considered as overhead costs. They may alternately be treated as regular working vehicles in which case they will carry a share of the overhead themselves.

Fixed costs must be recovered whether or not the vehicle does any work. The more vehicles, the smaller their individual share of the overhead cost. This recovery is usually achieved by charging a time-based rate for the vehicle, apportioning the fixed cost to the hours worked irrespective of the distance travelled. (This is important given that there is often significant time spent at terminals and at stops to allow boarding and alighting; i.e. the distance travelled does not reflect the productive use of the vehicle.)

How the vehicle-independent overhead costs are apportioned to different vehicle types in a mixed fleet is up to the operator. One possible approach, comparable with that commonly used in the freight industry, is to use passenger-spaces to determine the apportionment. The total number of passenger spaces in the operators fleet is determined and each vehicle carries overhead costs in proportion to its share of the total fleet capacity.

7.1.1.2 Variable costs

The variable costs of a vehicle are associated specifically with the use of the vehicle. Examples of variable cost elements are fuel, maintenance, and tyre costs. These costs are usually directly proportional to the distance travelled and are thus charged on a per-kilometre basis. (There may be a dis-proportionality given that public transport vehicles are required to stop frequently to allow boarding and alighting. Fuel and maintenance costs are associated with each stop although no distance is covered.)

7.2 THE COST MODEL

The DSS includes a cost model to calculate the fixed and variable costs for use in the vehicle allocation process. This model is in the form of a Microsoft Excel spreadsheet and interacts with the DSS database and thus the resource allocation model. The model is based on the Road Freight Association (1996) "Vehicle Cost Schedule."

The Road Freight Association (RFA) regularly publishes detailed costing sheets for a variety of vehicles. These are readily adaptable to suit the public transport industry. The RFA cost sheet has been transferred to a spreadsheet and modified to incorporate additional factors of relevance to public transport in general and the DSS in particular. This modified format can be used by operators and planners alike to estimate and graph the time and distance based charges for public transport vehicles. The model is also intended as an aid to determining the optimum economic replacement cycle for the anticipated operating conditions.

An abbreviated version of the data input component of the cost schedule is shown in Table 7-1, which is self-explanatory. The full version allows for trailers as well. These are not common in urban public transport and so are not included here although allowed for in the spreadsheet model. The form of the output from the spreadsheet calculations is shown in Table 7-2.

The calculations are performed in a spreadsheet, but the data for each vehicle type is entered and stored in the DSS database along with other vehicle specifications not relevant to the operating costs. (There is only one spreadsheet, not one per vehicle type.) When vehicle data changes, the database interacts, on command, with the spreadsheet to estimate revised costs. The spreadsheet results are returned to the database. The model is currently structured to take the user to the spreadsheet model but the spreadsheet may be run as a hidden module with minor adjustment to the code.

VEHICLE COST SCHEDULE

Vehicle type:	Single deck, standard bus	
Total Capacity	Passengers	60
Load factor		0.9
Design Capacity		54
Fare per kilometre		R 0.20
Prime mover or rigids :		
Cost Price. (excl.VAT)	R	R 394,883.00
Finance — cost of capital	%	19.80%
or — monthly repayment	R	R0.00
Depreciation — time	yrs	5.00
or — distance	km	0
Residual value. % of cost price	%	25.00%
Insurance as % of cost price	%	7.50%
Tare	kg	10300
Licence	R	4158
Tyre size and ply		1100X20 14
Number of tyres excluding spare	no.	10
Price of new tyre excl.VAT	R	R 1,762.00
Price of retread tyre excl.VAT	R	R 493.00
New tyre life : front	km	40000
New tyre life : rear	km	60000
Number of retreadings : front Note	no.	0
Number of retreadings : rear. Note	no.	2
Retread tyre life : front	km	40000
Retread tyre life : rear	km	60000
Number of steering axles	no.	1

Additional factor for split shift pay. Driver		0.1
Additional factor for split shift pay. Assistant		0.1
Maximum hours for driver and assistant.		12
Average kilometres travelled per hour worked.		34
Overheads		
Annual cost	R	0
or % of fixed cost	%	10.20%
Drivers		
Number of drivers	no.	1
Multiplier for extended hours.		1
Monthly remuneration	R	R 2,000.00
Assistants		
Number of assistants	no.	1
Multiplier for extended hours.		1
Monthly remuneration	R	R 900.00
Maintenance		
% of fixed cost.(Fixed maintenance.)	%	7.00%
% of running cost	%	26.10%
or cpk running cost	cpk	0
Fuel		
Consumption	l/100km	31.42
Price in cents per litre	c/l	204
Lubricants		
% of fuel	%	5.00%
Sundry		
Other variable running costs	cpk	0
Annual kilometres	km	91469
Days worked per annum	days	225
chargeable hours per work day	hrs	12.0

Note: Times a casing is retreaded before being replaced by a new tyre. Cpk = Cost per km.

Table 7-1: Vehicle cost schedule input data. (Demonstration data only.)

ANNUAL FIXED (STANDING) COSTS	**R**	**c/km**	**% FC**	**% TC**
Cost of capital (Finance.) (Note 1.)	R 39,054.32	42.7	19.80%	12.69%
Depreciation. (Note 2.)	R 55,708.45	60.9	28.24%	18.10%
Insurance	R 29,616.23	32.4	15.01%	9.62%
On vehicle staff	R 34,800.00	38.0	17.64%	11.30%
Overheads. (Note 3.)	R 20,121.22	22.0	10.20%	6.54%
Licence	R 4,158.00	4.5	2.11%	1.35%
Fixed maintenance. (Note 4.)	R 13,808.68	15.1	7.00%	4.49%
TOTAL ANNUAL FIXED COSTS	R 197,266.91	215.7	100.00%	64.08%
VARIABLE (RUNNING) COSTS	**R**	**c/km**	**% VC**	**% TC**
Fuel (Note 8.)	R 58,622.42	64.1	53.02%	19.04%
Lubricants. (Note 6.)	R 2,931.12	3.2	2.65%	0.95%
Maintenance. (Note 5.)	R 28,860.34	31.6	26.10%	9.38%
Tyres. (Note 7.)	R 20,162.14	22.0	18.23%	6.55%
Other	R -	0.0	0.00%	0.00%
TOTAL VARIABLE COSTS	R 110,576.01	120.9	100.00%	35.92%
TOTAL ANNUAL COSTS	R 307,842.92	336.6		100%
TIME UTILISATION				
Total number of hours worked p.a.	2700		**Profit Margin** 15%	
Fixed cost per day	R 876.74			
Fixed cost per hour	**R 73.06**			
Total annual fixed cost	R 197,266.91			
Total variable cost	R 110,576.01			
	Including profit			
VARIABLE COST per km	R 1.39	per period	R 565.17	
TOTAL COST PER km	**R 3.87**			
TOTAL COST PER HR	**R 649.19**	***@Speed***	***34***	***Km/hr***
		Over	***12.0***	***hrs***

NPV of One cycle at cost of capital.	**R 924,705.15**
Infinite period NPV at cost of capital.	**R 1,554,762.22**
Vehicle life cycle = depreciation time.	

Table 7-2: The output of the vehicle cost schedule calculations.

(Values for demonstration purposes only.)

Notes to Table 7-2:

1. Based on 0.5 x Cost Price x Interest rate. Estimates average interest component of monthly payments.
2. Initial cost - Residual value - 1full set of new tyres.
3. Includes for rents, admin staff and other associated expenses.
4. Includes time based maintenance such as associated with Certificate of Fitness inspections.
5. Estimates maintenance costs associated with distance travelled.
6. Based on fuel consumption.

7. A distance based function allowing for retreading. (There is a separate calculation table for tyre costs built into the spreadsheet.)

The main changes from the original RFA schedule are:

- on-vehicle staff split-shift factors for determining total salary costs
- a speed dependent fuel consumption rate (If calibration data is available.)
- an optimum life cycle function.
- two cost graphing options
- a separate profit allowance in the chargeable rates

From the figures, it can be seen that the data requirements are quite extensive, however common elements for different vehicles can be stored in a reference table in the database. With this arrangement, updated details for any item will then reflect for all vehicle types using that item. Fuel and tyre costs are the most common examples of this.

7.2.1 Vehicle costs in the resource allocation model

The resource allocation model uses the fixed cost per hour and variable cost per kilometre terms from Table 7-2 in determining the optimum allocation of vehicles. It would be ideal if the goal programme recalculated the vehicle operating costs to reflect route conditions, rather than using system average values. This may be implemented efficiently in the future but presently, imposes an undue burden on the solution process. Fortunately however, the fixed cost is more or less constant over time and the variable cost increases linearly with distance. (There may be discontinuities in fixed cost at the limit of allowed driver working hours. Over a certain number of hours per day, an additional salary expense is incurred.)

The result is that the problem of not including the vehicle operating cost directly in the vehicle allocation goal-programme is reasonably resolved by using the cost and GP models alternately in an iterative manner. Vehicle costs are initially estimated based on current or realistic, assumed conditions. These assumed conditions are an average operating speed, fare per passenger-kilometre, and a number of hours operated per day and days per year. (In fact, the planner must set up the vehicle cost and resource allocation models to reflect the same units of time, be they hours, days, or weeks.) The goal programme allocates the fleet according to these costs. The resulting average operating hours and travel distances are used to re-assess the vehicle operating costs. This process is repeated until a stable, or acceptable, allocation is achieved. Given that the vehicles are charged out for the full operating period, and thus that there are only a few possible values for the average working hours, the model will generally converge to a solution. Alternative starting points should be tested to ensure that the solution is not biased by the starting point, which could happen if the initially assumed hours and distances were too far from the optimal solution. (If the starting point is such that a vehicle's costs appear too high compared to another's, it may be rejected even though, it would offer an optimal solution if used.)

The use of average values, rather than route based values, is also less than ideal as route costs are not necessarily particularly accurate and will require route by route revision. The total cost estimate may be expected to be reasonable however. Given that once vehicles are operated over a certain number of hours, the total costs become relatively constant, this inaccuracy will be relatively minor in most cases. The planner must nevertheless be aware of this as a potential source of error for routes that take vehicles out of the average conditions, especially towards reduced operating hours. Operating speed may also be an issue where fuel consumption may be dramatically affected.

7.2.2 Minimising costs

Whilst certain costs, such as basic fuel price and licence fees are beyond the control of the public transport business, other factors can be controlled to a greater or lesser extent by the vehicle owners. For example, interest rates and bulk discounts on fuel and tyres and sometimes on the vehicles themselves can be negotiated. Fuel consumption can be minimised through good maintenance and driving habits and other costs can similarly be minimised. These opportunities are important and must be constantly kept in mind but are primarily in the hands of the operators. However, the planner may be forced to develop estimates of the costs, lacking better sources and thus needs to have reasonable estimates of all the input costs affecting the public transport industry. Most of these can be obtained through suppliers or central statistical services and are relatively system independent. Not all are however and in particular, fuel consumption represents a significant system-dependent cost element.

High fuel prices mean that the impact of the fuel price on the total operating costs can be significant and thus that any aspects of the system which impact on the fuel consumption should be examined for potential improvements. The spreadsheet cost model thus includes a fuel consumption formula that estimates the consumption as a function of the average operating speed. This assumes that calibration data is available for the vehicle type and is, even then, an approximation only. Where calibration data is not available, a fixed average consumption value can be used. This would be based on manufacturer or operator data.

Pienaar (1985) found a high degree of correlation between fuel consumption and travel time for public transport vehicles. The use of travel time implicitly takes into account the stop start cycle of public transport vehicles. The model was developed on the principle of equal travel in both directions, usual for public transport, thus reducing the impact of gradients on the route. The form of the fuel consumption model included in the costing model is from Pienaar (1985) and is given by:

Equation 7-1

$$B = K_a + K_b \cdot T \quad ml/km$$

Where: B = fuel consumption in (ml / km)

K_a = Calibration parameter.

K_b = Calibration parameter.

T = Travel time in seconds per km. $T \geq$ Optimum travel time, T_{opt}.

In the urban public transport environment, it is fairly normal for actual travel speeds to be low and thus for travel times to be higher than T_{opt}.

Pienaar gave the following values for K_a, K_b and T_{opt} for different public transport vehicles in South Africa.

Vehicle type	**K_a**	**K_b**	**T_{opt} (s/km)**	**Fuel type**
Minibus	59	0.826	60	Petrol
Midibus	74	0.906	64	Diesel
Single Deck Bus Front engine	196	2.129	72	Diesel
Single Deck Bus Rear engine	192	2.176	77	Diesel
Double deck bus	254	2.065	77	Diesel
Articulated bus	266	2.391	78	Diesel

Table 7-3: Fuel consumption calculation parameters for different vehicle types. (Pienaar 1985)

This table is contained in the DSS database and should be updated with more recent data if possible. In general, the average fuel consumption rates have improved since these values were established. Where different fuel consumption equations are commonly used in a region, the model may need to be modified. If no calibration data is available, the model will use the fuel consumption specified on the vehicle data sheet by the user.

7.2.3 Temporal issues

It must be noted that this model estimates "current" costs. The spreadsheet model does include estimates of the present value of both one life cycle and an infinite series of life cycles based on the specified depreciation period and cost of capital. These present-values have not been used in the allocation process but offer the potential to seek a long-term optimum-assignment of vehicles. There is however, no attempt to predict future costs for life cycle costing or to take into account the difference in capital cost between new and old vehicles. For smaller vehicles such, as mini-bus taxis, the expected life is usually relatively short, of the order of three to five years. The result is that for these vehicles, the total cost estimates will tend to be relatively accurate for all vehicles in use, long-term depreciation and rebuilding not being factors.

Large road vehicles however, may be expected to last and comply with the law for nearly thirty years allowing for rebuilding. (Non-road vehicles may have much longer lives but must, in any case, be treated individually by the relevant specialists.) The South African government draft tender public transport contract documentation (circa 2000) specifies the deemed age of a vehicle based on its original purchase date and rehabilitation or rebuilding. These restrict the deemed age to a maximum of fifteen years and this is probably the upper limit of the depreciation period specified for operating cost purposes even if the vehicle is actually much older. After rebuilding, this allowance then covers the cost of the rebuilding or rehabilitation.

In general, it seems that using two-thirds of the basic life expectancy as the depreciation period for a vehicle costing should provide a first estimate of cost. Thus, a mini-bus taxi would be depreciated over about two years whilst a standard bus would be depreciated over about ten years. Keep in mind that these are not tax or accounting values but estimates of the operating costs which must include allowance for the creation of a reserve fund to replace the current vehicle. In an inflationary environment, there also seems to be sense in using the current new vehicle price as the basis for determining the depreciation element of the cost. This will help to keep the replacement reserve at a level closer to the true replacement cost whilst keeping operating costs in line with current circumstances.

The final element to be considered in the vehicle costing process is profit. This is an element not included in the RFA schedules, but important in assessing the actual cost of the public transport system. How much is reasonable? Lacking better data from operators, ten to fifteen percent can be considered fair for estimating vehicle costs depending on the competition for the work. Individual operators may do better and others worse but the actual cost to the fare paying passenger and the subsidy paying authority thus includes an acceptable profit where services are provided under contract. The model provided here thus includes an allowance for profit on the cost of operating the vehicle.

7.3 VEHICLE COSTS AND OPERATING PERIODS

As mentioned earlier, resource allocation is a function of the distance and time-based costs of the different vehicle types. The total variable cost of operation increases in proportion to the distance travelled and thus to the hours operated. The time-based cost is an estimate of the hourly contribution of the vehicle to the fixed costs of the business. These must be recovered during the working hours of the vehicle, the time-based cost per hour thus decreases with an increase in the number of hours operated. As can be seen in Figure 7-1, the total cost per hour of operation also decreases with increased hours of operation. There is initially a rapid decrease in the average hourly cost, tapering off as the number of hours operated increases. From this, it can be deduced that vehicles should be run for some minimum number of hours, if at all, to achieve a reasonable total hourly operating cost.

At the same time, it can also be seen from Figure 7-1 that the maximum achievable revenue at a fixed fare is time dependent. This maximum revenue is given by:

Max Possible Revenue = Hours worked * Ave. Km/hr * Vehicle Capacity * Fare/km

The fare per kilometre is that received by the operator, not necessarily that paid by the passenger who may be subsidised.

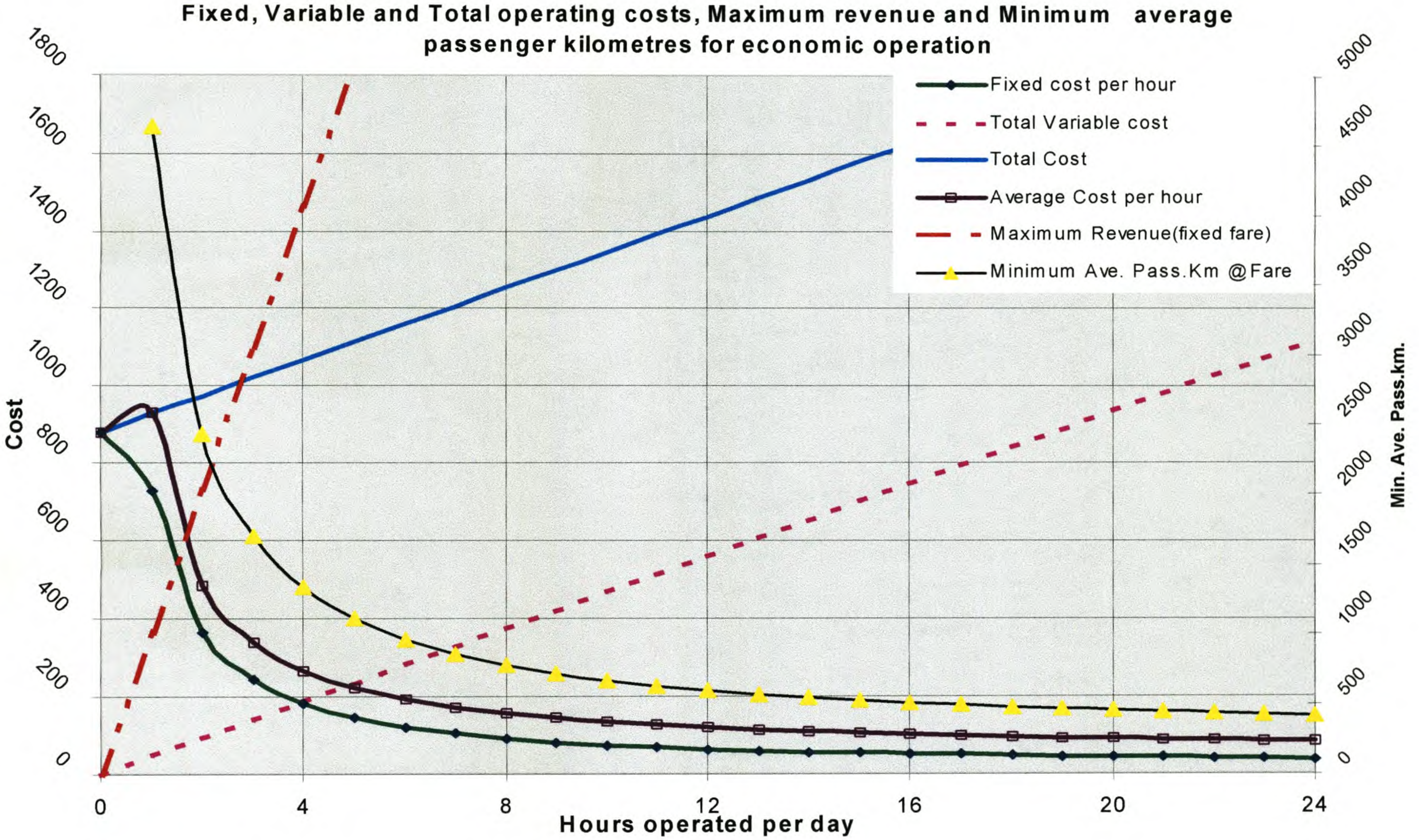

Figure 7-1: Vehicle operating costs and revenue against hours operated per day. Based on 225 days operation per annum.

Thus, the vehicle must operate for at very least as long as it takes the maximum revenue line to intersect the total cost line, and when the demand is adequate to keep the vehicle operating at capacity. In our example, this means that the vehicle needs to operate for at least three hours per day. In reality, the revenue is dependent on demand:

$$\text{Actual revenue} = \text{Demand(Passenger.km)} * \text{Fare/km}$$

This is usually somewhat less than the theoretical maximum revenue, often less than half. However, as long as the average passenger-kilometres per hour demanded exceed the minimum average required and shown in the figure, then a vehicle can be operated viably. This is very difficult to determine on a route by route and hour by hour basis. Thus although the information is of interest in analysing the performance of individual routes, the main object of its inclusion here is to demonstrate the need to establish suitable operating periods. These periods must be such as to ensure that vehicles can meet their costs, having sufficient average demand to ensure viability of the most suitable vehicle type. Too short or too long an operating period can move the system from viability into non-viability by lowering the average hourly passenger-kilometres demanded below the requirement for the most suitable vehicle.

These windows of viability for different vehicle types typically correlate with the conventional peak, off-peak system already most commonly used. It is worth the planners while however, to attempt an analysis of the demand patterns as it may be possible to improve performance by increasing or reducing the length of different operating periods. In particular, the degree of spread of the peak period associated with the larger vehicles in the fleet. This invariably means split operating periods for the vehicles themselves.

Split shifts are actually a potential advantage for all classes of vehicle. Public transport vehicles must at all times be kept clean, safe and in good condition; i.e. no broken seats or windows. If a vehicle is available for maintenance between 9 am and 3 pm, almost all routine maintenance and cleaning can be carried out during normal working hours. This reduces maintenance costs and the ability to see to minor problems promptly, improves the image of the vehicles in the eyes of the customers. Because the vehicles are maintained during off-duty hours (for the vehicles), the total fleet size can possibly be reduced and this reduces total costs further. It also tends to match typical demand patterns, allowing large vehicles to be operated during peak periods and small vehicles during off-peak periods.

7.3.1 Vehicle age

Vehicle age is a relevant factor in the total cost of operating a vehicle. Where a good market exists for second hand public transport vehicles, economic life cycle costing may be applied to estimate the optimum replacement cycle and thus total operating costs. Usually however, there is limited market for second hand public transport vehicles and thus economic life cycle analysis is of limited use, being based on the assumption of a good resale value. In this case other factors, such as availability for use may be a more important criterion. These techniques are discussed in section 7.4.

Given that vehicles may be kept for a relatively long time, the total costs may vary with the age of the vehicle. On the one hand, the older the vehicle, the more maintenance, and thus expenditure, is likely to be required. On the other hand, older vehicles have recovered all the capital costs associated with them when new and may thus be perceived as being cheaper to operate. This usually only applies to larger road vehicles and non-road vehicles. There is no hard and fast rule that can be applied to assess the optimum age for a vehicle, as it will depend on the quality of the original vehicle, its maintenance, and its use over its life. One vehicle may become dramatically more expensive with age while another may become cheaper. Each vehicle and vehicle type will thus have to be analysed independently.

For these older vehicles, the operating cost may be perceived as dependent on the utility to be derived from the vehicle. This utility is made up of two main components:

- The serviceability of the vehicle; i.e. the number of hours per day or week that it can be expected to be available for duty.
- The perception of the vehicle held by the customers. They may be unwilling to travel on old vehicles and thus the fare revenue (passenger kilometres) and reputation of the public transport system are diminished. (The lost revenue and image are a cost.)

The first of these is readily determined from vehicle records for the existing fleet will be discussed in section 7.4. The second is rather subjective and may produce surprises, old vehicles sometimes being more popular than new ones. This is discussed in section 7.4.3.

7.3.2 Economies of scale

Another important component of the overall cost of operating a vehicle lies in the maintenance of the vehicle. This maintenance includes the acquisition of spare parts, including tyres. The operator with a large fleet is in a far better position to obtain discounts from suppliers than the owner of one or two vehicles. Similarly, maintenance facilities, which are able to take advantage of off-peak periods and night shifts, are only feasible when the fleet is of sufficient size to support dedicated facilities. These may be managed by an individual operator or the vehicle manufacturer as a service to all operators of the vehicle type.

There are also issues of standardisation. Spare parts will be slightly cheaper and can be kept in stock economically when there are many similar vehicles. Maintenance tasks will be carried out more speedily due to familiarity and tooling and drivers will be able to transfer more readily from one vehicle to another. Generally, it is to be expected that the answer lies in having a limited range of vehicles in terms of capacity and manufacturer. In other words, only two or three sizes of vehicle and all from the same manufacturer should offer some benefits.

Determining exact values for any of these benefits is difficult and can only be achieved through experience. There can be little question however, that some degree of standardisation must offer some benefits. If the planner is able to obtain any estimate of the benefit, this can be used to modify the vehicle cost estimate. It is also worth determining whether or not a central maintenance and spares facility could not be made available to the entire system as an auxiliary function. This could be independent of any operator or operated as a standalone entity by one of the operators on behalf of the local transport authority.

7.4 VEHICLE REPLACEMENT CYCLES

Public transport vehicles of all types will eventually need replacement. The direct cost of providing the service as well as the impact of the image of the public transport system on capturing and holding customers are influenced by the replacement decision. There is thus a need for both operators and the transport authority to have some method of evaluating the best replacement cycles for public transport vehicles. The replacement decision is based ultimately on financial considerations but these may be influenced by a number of factors not normally considered in vehicle replacement cycle decisions. The following are issues that may not be relevant to other vehicle types:

1. The appearance and condition of the vehicle may have an impact on its earnings. Choice, and even captive, riders of public transport may be discouraged from using public transport where vehicles are perceived as being below expected standards. It may be possible to

charge premium fares on some routes for suitable vehicles. There is also the image value of new vehicles to be considered which may play a significant role in the choice user's decision.

2. There are legal restrictions governing the age of public transport vehicles operating on the road.
3. Due to the relatively mild operating conditions of public transport vehicles, within the legal limitations, rebuilding of vehicles is a feasible option. It is quite common practice for operators of large vehicles to keep them for the full duration of their legal life.
4. Many public transport vehicles are extremely expensive to buy new but have a very long useful life. At the end of their useful life they usually have no resale value other than as scrap.
5. The resale of road-mode public transport vehicles, especially those at the end of their legal public service life may pose some problems. Once the legal life is over, the vehicles have only scrap value. Before that, selling them locally is potentially a problem as their use by the competition may be considered a disadvantage if the competition is willing to buy them at all given the image component of their value. It is common amongst larger operators to scrap, rather than sell on, their older vehicles.

Irrespective of the issues that do affect the replacement decision, it is still necessary to carry out some basic economic evaluations. Cooke (1974) describes a number of techniques for the evaluation of vehicle replacement cycles. Although Cooke does not deal specifically with public transport vehicles, for service vehicles he suggests a productivity oriented replacement policy that includes considerations relating to the latter two points. This policy is based on the conventional economic replacement cycle but uses the cost per day available for use as the basis for assessing the replacement cycle.

7.4.1 Minimum average annual cost replacement cycles.

The conventional approach to vehicle replacement cycle analysis is to minimise the long-term cost of owning and operating the vehicle. The replacement cycle objective may thus be stated as:

> Minimise the net cost of the vehicle (Maintenance costs + purchasing cost – trade in value) in the long-term.

Mathematically speaking:

Determine n such that V(n) is a minimum where:

Equation 7-2

$$V(n)=\left(\frac{1}{\left(1-(1+r)^{-n}\right)}\right)\left(C+\sum_{i=1}^{n}\frac{R(i)}{(1+r)^{i}}-\frac{S(n)}{(1+r)^{n}}\right)$$

V(n) = the net present cost of owning the vehicle over an infinite period given replacement every n years. The first term is the infinite chain factor.

C = current capital cost of vehicle.

n = number of years in operating cycle.

R(i) = total operating cost in year i, allowing for inflation.

S(n) = residual value of vehicle in year n allowing for inflation.

r = discount rate reflecting required return on investment allowing for inflation and taxation.

This method requires that the future maintenance costs and residual value be predicted for each year into the future and then discounted back to present values. This is usually achieved by using historical data showing how vehicles of different ages and types have performed. Failing such information, simple inflation rates may have to be used. The cost model presented in Section 7.2 can be used, with care, to assist in determining the total costs. In particular, the fixed costs must be determined taking into account that the replacement cycle is affected by such issues as tax allowances. The detailed application of this process is described in a number of texts, including that of Cooke (1974) and is not dealt with in detail here.

The method is based, but not dependent on the assumption that, ignoring inflationary effects, the maintenance costs will increase with age and that the residual value will decline. A well-maintained vehicle may however have relatively static maintenance costs for many years and public transport vehicles are inclined to have limited resale value at any stage. Given that public transport vehicles are constantly in the public eye and that vehicle safety is a very high priority, public transport vehicles may reasonably be expected to receive excellent maintenance from the very start of their lives. In other words, there should be very little impact on the annual cost of operating a public transport vehicle, due to vehicle age, until major rebuilding is required. Even then, the rebuild is likely to result in a lower overall cost than a new vehicle for the remaining years of its legal life. Of course, once the legal maximum vehicle age is reached the vehicles must be replaced irrespective of their operating costs.

This leads to the authors assertion that whilst fleet managers must carry out the exercise as part of overall cost management, the use of economic replacement cycle techniques on their own is of limited use in the public transport environment. Unless there is a demonstrable market for used vehicles or there is a significant increase in maintenance costs with age, the result is likely to imply that vehicles be kept as long as possible. (This is what commonly happens in practice.) The main complication in carrying out the evaluation lies in determining the annual values rather than the actual analysis, although that can be complicated enough. For this data acquisition, there is no short cut and the matter is thus allowed to rest there, except to note that two Lingo models have been provided with the DSS to allow the planner to test replacement cycle policy. One is based on user provided data for every year whilst the other uses inflation factors to project increased costs. These may be found on the accompanying CD as Replace2.lg4 and Replace4.lg4.

7.4.2 Productivity index replacement cycles

A modification of the minimum average cost approach to vehicle replacement cycles exists that is also commonly used for utility vehicles, such as refuse trucks, fire engines and ambulances, none of which have much use outside their original design function. The method seeks to optimise the life cycle in terms of the cost per hour available for work.

This approach proceeds much as in the previous section except that now, for each year of its life, the number of productive days is estimated for the vehicle. This is determined from the maintenance history of the existing vehicles. From this history, it can also be seen what the ratio of labour hours to out-of-service hours is. Cooke (1974) suggests that typically a vehicle should be assumed out of action for an entire day for each four hours of work required. Thus, a vehicle in its rebuild year might only be available for half the working year.

Proceeding as per the conventional economic evaluation V(n) is calculated as:

Equation 7-3

$$V(n)=\left(C+\sum_{i=1}^{n}\frac{R(i)}{(1+r)^{i}}-\frac{S(n)}{(1+r)^{n}}\right)$$

Where all variables are as in Equation 7-2 but the infinite chain factor is not included.

Then for some finite total period, say 30 years, the net present value of operating each cycle is determined. In fact, it will be necessary to use several such periods to allow for comparison of different multiples. For example, in the following table, a two-year replacement cycle acts as an index to cover a range of possible cycles:

Cycle length, Years:	1	**2**	3	4	5	6	7	8
Occurrences in 30 years:	30	15	10	-	6	5	-	-
Occurrences in 56 years		28		24			8	7

Table 7-4: Establishing an index for a range of possible life cycle lengths.

The total number of working days available from the vehicle in the total design period is determined for each possible replacement cycle, of n years. This is explained in the following example:

Assume 225 working days per year and a 30-year evaluation period. Assume that a vehicle is able to work 220 days in its first year. Then, if the vehicle is replaced every year, 220 days will be worked in every year at an average cost of:

$$V(1) \times (1+r)^{30} / (30 \times 220) \quad \text{per day}$$

If the vehicle is kept longer, the number of available days in each year drops so that a five year old vehicle may have provided $220 + 218 + 215 + 210 + 203 = 1066$ days in five years or $6 \times 1066 = 6396$ days in thirty years. This is as opposed to the 6600 that would have been worked with a new vehicle every year. The average daily cost is now:

$$V(5) \times (1+r)^{6} / 6396 \quad \text{per day}$$

(The net present value of the cycle over a long but finite period / total hours available in that period.) This is done for all possible replacement cycles and the life cycle with the minimum daily cost is then chosen as the optimum cycle. Again, a detailed description of the process can be found in Cooke. A Lingo model is provided on the CD to demonstrate this principle. The file name is Productivity.lg4.

It may be noted that the reliability also affects the number of "spare" vehicles required in the fleet. The need for standby vehicles imposes a burden on the operator that is inversely proportional to the size of the operator's fleet. The small operator, required to have one extra vehicle, may be in a far worse position than the large operator needing ten extra vehicles, and a different replacement policy may be justified. This is an important issue in contracted public transport services where penalties are imposed for failing to perform. If the relationship between additional vehicles and reliability can be determined then reliability has an added advantage as a replacement cycle estimation technique.

7.4.3 Customer perceptions and company image as replacement cycle estimators

No matter that the optimal cycle determined by any logical and rational means is the longest legal cycle, there may be good motivation for replacing vehicles earlier. Although the vehicle may be in perfect condition, customers may perceive them as being unsatisfactory. Much of this has to do with image and comfort. In these circumstances, it is necessary to assess the value of the companies image, and. there can be no doubt that a fleet of shiny new vehicles is more likely to attract choice riders. This is not however guaranteed, as was demonstrated in San Francisco where 60 and 70 year old street cars were reintroduced and resulted in a nearly doubled route ridership. (TCRP Report 46, 1999.)

Measuring the image value and "marketability" of vehicles of different ages is no simple matter and requires special techniques, stated and revealed preference surveys being a useful starting point. Revealed preference may be tested by observing customer behaviour on selected routes where only the newest vehicles are placed. Interestingly, Prioni and Hensher (1999) concluded that the vehicle quality had little impact on user perceptions. The study was however conducted in Australia and it is suspected that the difference in quality between the best and worst was limited and that the general standards were high. This finding also contradicts the observations of the operators in the United States, cited above. In South Africa, there is at least some perception amongst non-users that the quality of the vehicles is inadequate. An accurate measurement of the impact of the vehicle age and quality is not necessarily that easy to obtain but could and should be developed over a period.

Although the concept of image and user perception is mentioned in a number of texts, the writer has not come across any method other than that proposed by Prioni and Hensher for estimating replacement cycles based on user perception. It is possible however, that tour operators may be able to provide the public transport industry with some guidelines on this.

7.5 REFERENCES

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8 INTERCHANGE FACILITIES

One of the outputs of the DSS is an estimate of the number of times that each node and link in the network is used by a public transport route and whether as an intermediate element or a terminal element. This data is enhanced by the results of the Emme/2 (INRO 1999) transit assignment from which the number of boardings and alightings at each node are obtained for the period being modelled. With this information, it is possible to determine both the vehicle and passenger capacity requirements of the facilities at each node. Of course, since the Emme/2 model only reflects one operating period, it may be necessary to evaluate the node usage for several periods. The DSS stores the last entered infrastructure type for a node irrespective of the period being modelled. Thus, the planner can evaluate the node requirements for each period, after which the node data will reflect the infrastructure type required to support the busiest period albeit that different nodes have peak usage during different operating periods.

The term interchange facility is to be interpreted as including all places where passengers may board or alight from a vehicle of any type and so includes simple bus stops as well as full multi-modal interchanges. The nature of these facilities can have a significant impact on the performance of the public transport system for two reasons:

- Each such facility has a capital and maintenance cost and the potential to generate revenue.
- The customers and potential customers will be influenced in their mode choice by their perception of the interchange facilities.

8.1 WAITING TIME AND TRANSFERS

Two of the more unsatisfactory aspects of public transport travel are the need to wait for and to transfer between vehicles. Operating services at the highest possible frequency and ensuring co-ordination between services reduce waiting time. Achieving such maximum frequency in turn tends to increase the number of transfers required as different vehicle types are employed to economically maintain the frequency at lower and lower demand levels. It is thus impossible to eliminate both waiting time and transfers. This being the case, the best must be made of what cannot be eliminated.

As pointed out by Vuchic (1981,) transfers need not be that onerous given two conditions:

- Transfer times are short. Poor co-ordination of services with large discrepancies in service frequencies can lead to extended waiting times which are likely to result in the loss of customers to alternative modes.
- The transfer environment is pleasant or even attractive. (The author believes that creating the pleasant or attractive environment is a potential source of revenue for the public transport system rather than an additional cost.)

8.1.1 Waiting time

Even given a pleasant transfer environment, the need for minimising transfers and transfer time remains. The concept of timed transfer is proposed by Vuchic et al (1981) as a technique for achieving this transfer time minimisation. This scheduling process relies on pulsing the arrival and departure of vehicles to and from "focal points" on the network. The idea is that vehicles from all routes serving a focal point should arrive, stand at and depart from the focal point at the same time so that passengers can transfer without waiting. This system has the difficulty of requiring specific relationships to exist between lines in terms of cycle time if capacity is to be reasonably managed with only one vehicle type. This problem becomes greatly aggravated when there are as many focal points, as there will be in a large city. The technique does not deal specifically with the problems of the number of transfers required and the initial waiting time, which can really only be dealt with by increased service frequencies.

The route extraction technique proposed in this dissertation seeks to minimise transfers by providing routes with two properties:

- With origin-destination pairs of matching demand, starting with the highest demand.
- Able to make use of different vehicle sizes to offer maximum network coverage and service frequency.

These factors are discussed in other chapters and are thus not discussed any further here.

8.1.2 The transfer environment

One approach to achieving a pleasant transfer environment is the commercialisation of public transport access points, of any size. This opportunity is exemplified by the shops that the large oil companies have established at their outlets. At local bus stops for example; What better than to be able to buy your ticket while you wait, (maps and timetables for new users,) or milk and bread on your way home? This offers an opportunity to create jobs, make public transport safer and more convenient and to market public transport. If locals use the shop, they will become familiar with the public transport and may be tempted to try it. It is not as improbable as it sounds either — in many of the world's cities, even the major ones; tiny pavement shops abound and flourish. The use of local shops acting as ticket agents and even holding areas for long distance bus routes is also quite common practice. In South Africa this commercialisation of public transport access-nodes may further offer a partial solution to the current street trader problem. This is however, a separate issue.

Central to establishing the nature of a transfer facility, be it a bus stop or an international airport, is a knowledge of its utilisation. The DSS is intended to aid in determining both the location and nature of transfer facilities.

8.2 INFRASTRUCTURE SITING

Although the siting and design of bus stops, stations, interchange facilities, and terminals is a process which can only be properly entered into once the route network design is nearly complete, the route extraction process is the first step in such a design process. As the routes are extracted from the link demand data, the database record for each link and node used by a route is updated to reflect this use. The result is that at the end of the extraction process, over and above the geographical information, the following is known for each link and node:

- Number of routes passing along the link or through the node.
- Times used as a start link or node.
- Times used as an end link or node.

The resource allocation process then determines the types and number of each type of vehicle required to operate each route. This information makes it possible to estimate the number of and characteristics of the vehicles using each node. (The number of vehicles is an estimate because the Emme/2 Transit modelling process may result in changes to the overall vehicle numbers.)

Once the routes have been fully defined, they are subjected to the Emme/2 transit assignment process. The results of this process are very much dependent on the transit assignment parameters used in Emme/2. These parameters reflect the impact of boarding, waiting and walking. The Emme/2 manual (INRO 1999 pages 4-397 et seq. and elsewhere,) describes these in some detail and they are thus not discussed in detail here. It must be stressed however that these parameters and the definition of the lines significantly influence the Emme/2 transit assignment results. In particular, there can be no boarding and alighting at a node where the line does not stop. Since the route definitions include all nodes on the route, the use of a universal dwell time will result in users transferring at any and all nodes even though it would not actually be reasonable to allow a transit stop at many of the nodes. Nodes must thus be marked as being or not being stops as the case may be. This is done in Emme/2 using the dwell time for each node. The transit line export function sets the dwell time based on stop markers associated with each node in the network.

The DSS route extraction process incorporates a mechanism for determining which nodes should act as stops and which not. The nodes are marked independently of the route design being assessed as potential stops by establishing for each node, how many active links are attached to each node. In this case, a link is perceived as two-way where it is not specifically one-way. Any node to which more than two demand-carrying links attach must be a potential stop, either for pedestrian access or for route transfer. All nodes that act as route start or end nodes, as determined during the extraction process, are naturally stopping points. The planner may naturally further modify the stop indicators manually.

The following information is obtained from Emme/2, after the transit assignment process, and is imported into the DSS and incorporated into the node data:

- Initial boardings
- Transfer boardings
- Through passengers
- Final alightings
- Transfer alightings

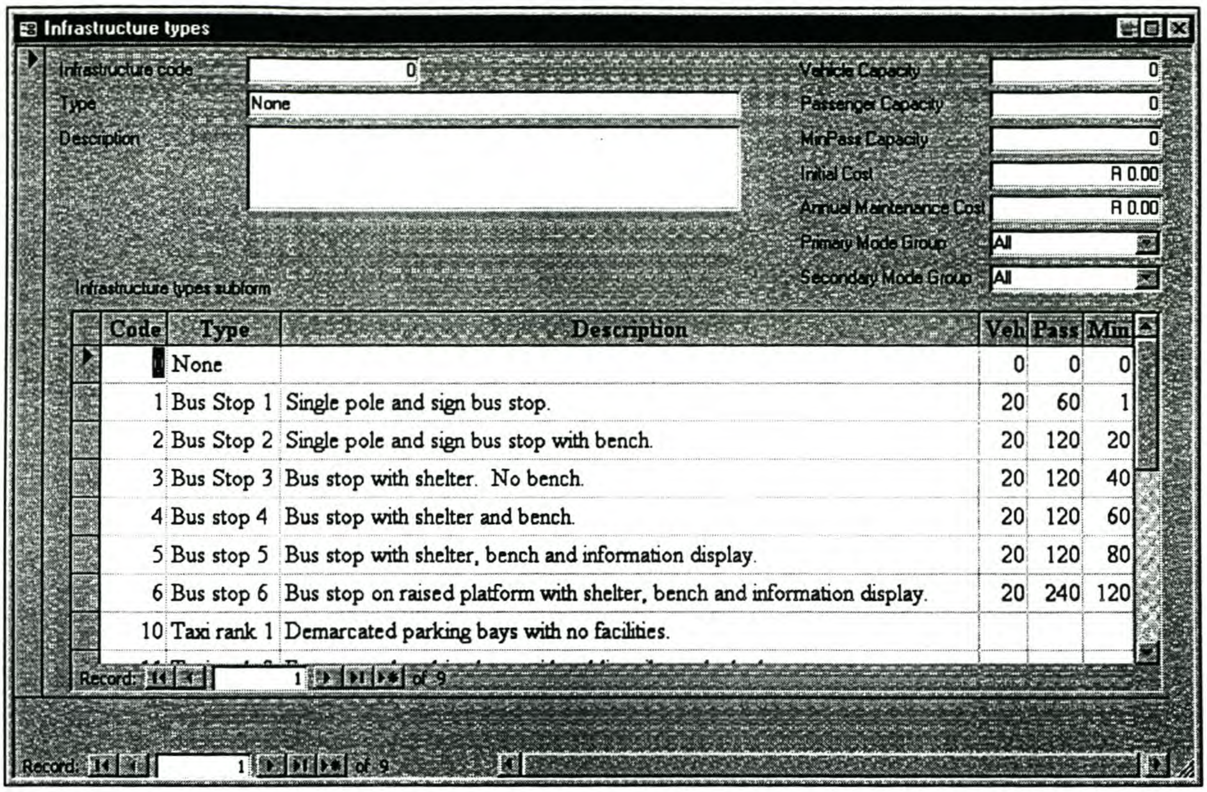
With this data, it is possible to determine whether a node should be used as a stop, an interchange or a terminus and thus to make the best allocation of funds to fixed infrastructure based on demand levels. For example, a node through which only one route passes is unlikely to have significance other than as a potential local stop. Where the node is at the end of a centroidal or walk mode link, then there may be significant boarding and alighting at the node, signifying the need for a facility based on the demand. Other nodes may reflect only very limited boarding and alighting and must be considered for stop siting at the local operational level. A node through which several routes pass must be considered as a site for a transfer facility. Vuchic (1981, Sect 5, pg. 72,) refers to these points as "transit centres" which he categorises as On-Street or Off-Street transit centres.

In each case, there are a number of factors to be considered, once again from Vuchic (1981, Sect 5, pg. 81,):

- Terminal capacity
  - Vehicles
  - People
- Transfer directions of passengers
- Express line provisions
- Passenger services

In respect of infrastructure siting, it may be argued that infrastructure is fixed and that one cannot move it. This is only partly true however. Transport demand is dynamic and circumstances change. This being the case, the planning process should be repeated every year with the most up to date data although the changes implemented, if any, may be minor. Modification of routes may however occur, especially for low-demand road-based routes, as new housing developments come on line. There is no reason why instead of permanent bus stops, portable bus stops should not be used. These could be based on the principle of the shipping container and be easily transported and loaded or offloaded wherever needed with little preparation of the site. Once a node is established as a more significant interchange point, it seems reasonable to assume that unless the entire public transport system goes into decline or there is a very significant urban change, the node will be maintained or even grow as an interchange.

The process of selecting the facilities is enabled through a number of tables and forms in the DSS. The most important of these is the table that provides a guideline as to the type of infrastructure to be employed given a certain level and type of demand. The data form is shown in Figure 8-1. With the exception of the "MinPass Capacity" field, the information is self-explanatory and is thus not discussed further. The "MinPass Capacity" represents the minimum level of demand for which an infrastructure type should be implemented. Thus, with less than 60 passengers per hour in the peak hour, nothing more than a code 3 stop should be provided.



Infrastructure code: 0
Type: None
Description:
Vehicle Capacity: 0
Passenger Capacity: 0
MinPass Capacity: 0
Initial Cost: R 0.00
Annual Maintenance Cost: R 0.00
Primary Mode Group: All
Secondary Mode Group: All

Infrastructure types subform

Code	Type	Description	Veh	Pass	Min
0	None		0	0	0
1	Bus Stop 1	Single pole and sign bus stop.	20	60	1
2	Bus Stop 2	Single pole and sign bus stop with bench.	20	120	20
3	Bus Stop 3	Bus stop with shelter. No bench.	20	120	40
4	Bus stop 4	Bus stop with shelter and bench.	20	120	60
5	Bus stop 5	Bus stop with shelter, bench and information display.	20	120	80
6	Bus stop 6	Bus stop on raised platform with shelter, bench and information display.	20	240	120
10	Taxi rank 1	Demarcated parking bays with no facilities.			

Figure 8-1: The infrastructure data used to select a suitable facility for each active node in the public transport system. (The data is for purpose of example only.)

8.3 REFERENCES

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9 CASE STUDY

9.1 INTRODUCTION

This chapter presents an example of the use of the public transport route design process described in the preceding chapters. The decision support system described in this dissertation is based on the assumption that a standard transport network model of the study region already exists. In the case study presented here, the Winnipeg model is used in that context. The Winnipeg model forms part of the Emme/2 installation. This model includes existing public transport lines against which those produced by the model can be compared.

In general, the example is based on the simplest of the possibilities that exist, inasmuch as that:

- Only one design period is considered.
- The model only has a road mode network.
- Only two vehicle types are available.
- One-way links have been ignored although there are several of them in the network.

The case study example is also presented on the basis that the process details have already been described elsewhere. Consequently, except where it adds to the earlier description, only the most basic commentary is given here although every step is listed.

9.2 SETTING BASIC DESIGN PARAMETERS

The first step in the design process is the establishment of the design parameters. For the case study, these are limited to:

- Attempt to achieve a minimum service frequency of 4 vehicle per hour based on the smallest available vehicle – a 14 seater with a utilisation factor of 0.9.
- Express routes should be based on a minimum origin-destination demand of at least 20 trips per hour and distance of at least 5 kilometres. The minimum express demand should be not less than 50 passengers per hour.
- Only traffic factors are to be considered; i.e. there are no urban planning type policy factors to be considered.
- The design is only required to cater for current demand.
- No route may have more than two vehicle types operating on it.
- The system must operate without any subsidy in the design hour.

- In order of priority:
    - Demand should be met.
    - Policy frequency should be attained.
    - Only currently available vehicles should be used

Once the parameters are established, the process can proceed.

9.3 PREPARING THE NETWORK

The first step is to make a copy of the base scenario or model. In this case, Scenario 1000

Scen. 1000 (DME AA):>WINNIPEG 1981 ROAD AND TRANSIT NETWORK

has been copied to create:

Scen. 3000(--- AA): AM MultiClass Assignment

Once the new scenario has been created, the following modifications must be considered although not all are applied.

- The transport demand matrices.
- The average vehicle occupancy rate for the public transport vehicles.
- *Volume delay functions* for dedicated public transport links.
- The creation of a "Policy Attribute" for each network link.
- The mode definitions used in the modelling process.

9.3.1 The demand matrices

In the public transport planning process, the auto demand is assigned as a secondary class. This requires that the auto demand matrix is presented in terms of vehicle, not person demand. In order to do this; a new private demand matrix is created by dividing the person demand matrix by the vehicle occupancy matrix. The auto demand is given in vehicles in the Winnipeg case and so no modification is required.

The public transport demand matrix reflects current demand. Since the planning requirements, specified earlier, only require modelling for current demand, no modifications are required. Had there been a requirement for such modifications, such as a demand growth factor, they would be performed at this point.

9.3.2 Vehicle occupancy modifications

A vehicle occupancy rate for the public transport vehicles is required. For this, a new scalar matrix is created:

ms01: TrnOcc	Transit occupancy	Default value = 14

9.3.3 Volume delay functions

The case study contains only road mode network elements. Consequently, there is no need to construct volume delay functions for non-road mode elements. However, the model contains a significant number of links, which carry only bus or pedestrian modes. These links have no volume delay functions and are specified as having no lanes. For the sake of the case study, these links are all set to have one lane and a volume delay function. For the bus lanes, an existing volume delay function has been used:

fd14 = length * (1.4493 + (.001098 * (volau + volad) / lanes) ^ 5.7894)

This setting is carried out by selecting the links having only modes b and p in the base model.

Strictly speaking, a volume delay function should be developed for the bus lanes but this is naturally not possible in this case. The selected function has characteristics which make it a reasonable choice: Relatively low travel time for small vehicle volumes with a rapid increase in travel time once this volume is exceeded. Keep in mind that each 14 passengers represent one vehicle. The increase in travel time arises out of the interaction of the transit vehicles when entering and leaving the stream and when stopping for passengers.

Links that carry only pedestrians also form part of the public transport network and have associated with them a travel time and thus cost. In this case, a volume delay function:

fd41 = 20 * length

is created and assigned to all links with only modes a in the base model. This is the equivalent of the 3 km/h specified in the mode definition for the transit access mode a.

These volume delay functions are required for the multi-class assignments. For the single-class assignments used in the focusing process, the link travel times are used in place of conventional volume delay functions. We thus create a new volume delay function:

fd42 = ul1

Where: ul1 will be set equal to the link travel time for the link after the first multi-class assignment.

Finally, in order to split the public transport demand matrix into express and regular demand, we need to establish the shortest paths between every origin-destination pair. For this, a volume delay function representing link length only is required. We thus create:

fd45 = length

9.3.4 Policy factors

There are no urban planning policies to be considered and so no policy factors need be included in the cost. Had such policies been required, one of several options could have been applied. For example:

- The base network data could have been imported to the DSS, the street names added and the policy factor been added to the network data based on street name. The revised network would then replace the current one. The policy code would later be used as a selection criterion to modify the demand penalty.
- An extra link attribute could be created and then modified to reflect the demand penalty change for each link based on some link attribute, such as "link type."
- An extra link attribute could be created and then modified to reflect a policy code for each link on a link by link basis. This code would later be used as a selection criterion to modify the demand penalty.

9.3.5 Mode definitions

The final modification required is to the mode definitions on the network links. All links, irrespective of current mode, are to be able to carry the transit mode. This is performed using a macro. The macro "MODECHNG.MAC" is given on the CD in \Emme2\Macros.

In essence, the process is as follows:

- Provide the macro input data.
  - ➢ Specify the name of the current auto mode. In this case, c.
  - ➢ Specify the name of the new auxiliary auto mode, to replace the current auto mode. In this case, q.
  - ➢ Specify the name of the new auto mode to represent all transit. In this case, t.
- Create the new auxiliary auto mode, q, in the mode table.
- Add the new auxiliary auto mode, q to all links currently carrying auto mode
- Delete the current auto mode from all links.
- Delete the current auto mode from the mode table.

- Create the new auto mode, representing transit, in the mode table. In this case, t.
- Enter operating coefficients of new auto mode.
- Add the new auto mode, t, to all links in the network.

Once this is done, all basic network modifications are completed and the first multi-class, generalised-cost assignment can be performed.

9.4 THE NETWORK MODELLING PROCESS

9.4.1 The first multi-class generalised-cost assignment

The first multi-class generalised-cost assignment is used to determine the travel times on all links when the public and private transport demand are assigned simultaneously. (In the focusing process, the resulting link travel time is used instead of the link volume delay functions.) In the example, the generalised-cost for the transit demand is the link length with a weight of 0.1. The objective of the latter is to seek the shortest physical path from amongst paths of equal or nearly equal travel time.

The assignment details are as follows:

```
An auto assignment has already been performed on scenario  3000:
Extra fct. parameter: el1:  ul1
Class 1:            Mode: t (AllTransit)
..... fixed costs:   0.10000*length
Demand:               mf02: gpqtr0/r  transit demand dpr0000
Vehicle occupancy:    ms01: TrnOcc    Transit occupancy.
Class  2:           Mode: q (AuxAuto   )
..... demand:        mf01: wod76d/r  1976 observed auto demand
(vehicles)
Stopping criteria:   iter=  15     rgap=  0.50%    ngap=  0.50
Number of iterations:   11          stopped by: ngap
```

The travel time results of this assignment are shown in Figure 9-1.

The link travel times determined in this multi-class assignment are saved to a user link attribute for use in the focusing process. In the case study, ul1 has been used. The scenario is now copied to a new scenario:

Scen. 4000(--- AA): First single class assignment.

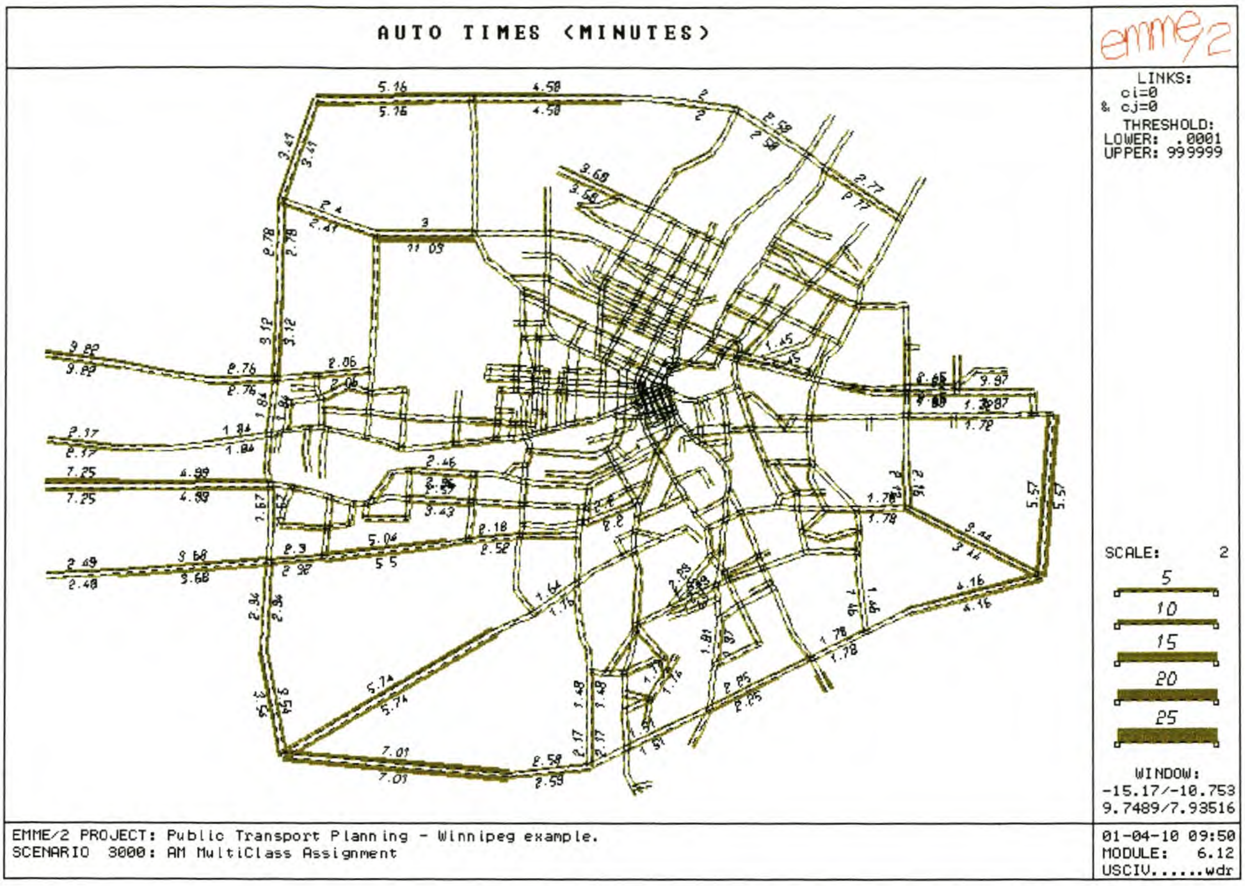


Figure 9-1: Network travel-times as predicted by first multi-class generalised-cost assignment.

9.4.2 Setting up the first single class-assignment

Two modifications to the model are required before proceeding with the focusing process.

9.4.2.1 Express and regular demand matrices

It is often possible to isolate potential express routes from the demand matrices. In the design specification, it was required that origin-destination demand of over 20 trips in the design hour and for distances of greater than 5 km were required for express route consideration. It is thus necessary to split the transit demand matrix into two to represent this. This process is described in detail in APPENDIX E and must be carried out before the following step. The result is two matrices:

mf09 = The express demand, i.e. that satisfying the express route criteria.

mf10 = The regular demand, i.e. that not satisfying the express route criteria.

9.4.2.2 Volume delay functions

Since in the focusing process, the link travel time derived from the multi-class generalised-cost assignment is used, the volume delay function in the new scenario, Scenario 4000, is set to fd42 for all links. The result is that link travel times are now volume independent in further assignments.

9.4.2.3 The express assignment scenario

The current scenario, Scenario 4000 is used to start the focusing process for the regular demand. A separate scenario is required to accommodate the express demand assignment. Scenario 4000 is thus copied to Scenario 10000:

Scen.10000(--- AA): Express -> O-D demand >= 20.

9.4.3 Express demand assignment

The express demand is now assigned to the network on its own according to the following:

```
An auto assignment has already been performed on scenario 10000:
Extra fct. parameter: el1:  ul1
..... fixed costs:    0.10000*length
Demand:               mf09: EXPRSS    Express demand
Stopping criteria:    iter=  15      rgap=  0.50%     ngap=  0.50
Number of iterations:    2           stopped by: ngap
```

The result of this assignment of the express demand is shown in Figure 9-2. This shows the demand on the best generalised- cost paths where the generalised-cost is given by:

Generalised-cost = Link travel time + 0.1* Link length

This is the same as for the multi-class assignment.

There may be some justification in carrying out focusing steps on this assignment. In this case however, Figure 9-2 implies that the demand is sufficiently well focused already. That is, there are not many paths of low demand, but rather, quite clearly defined paths of demand.

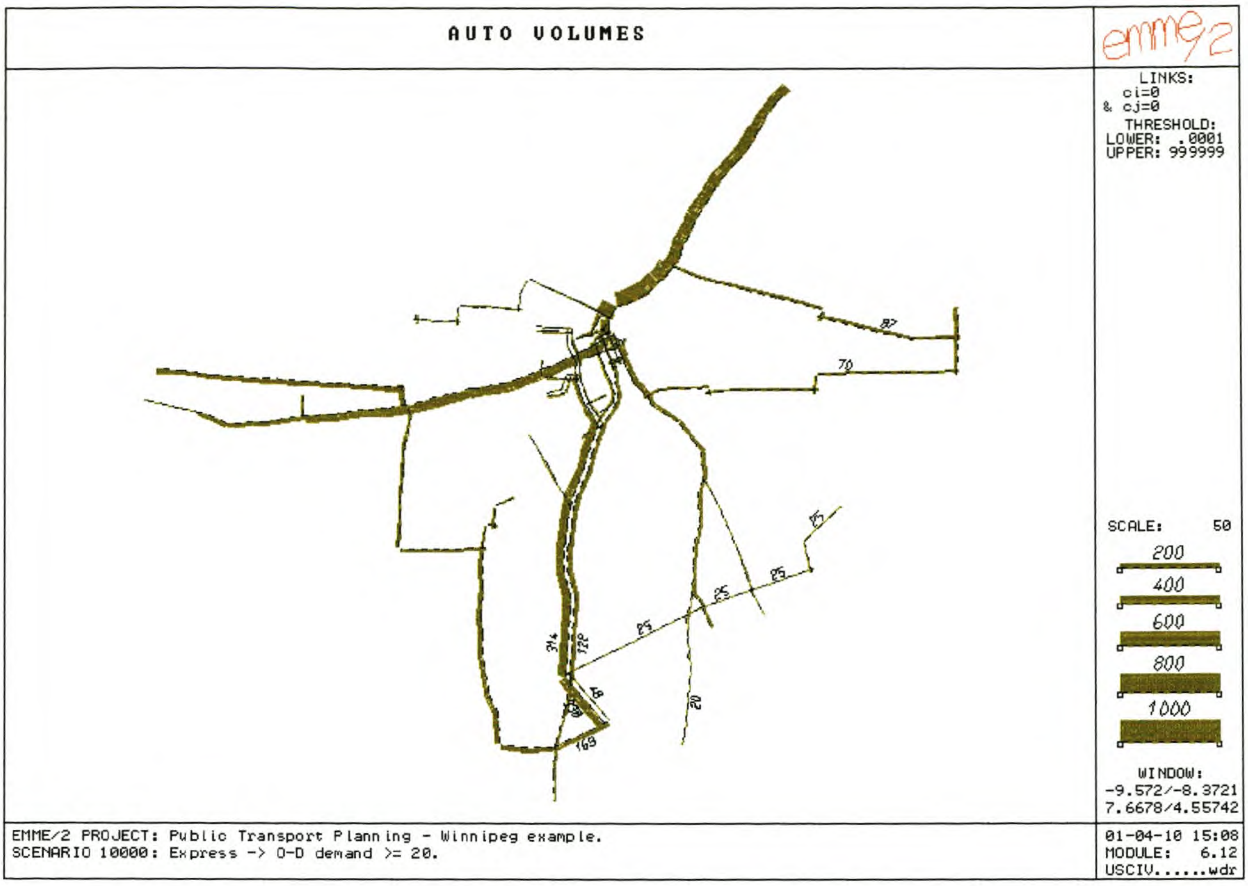


Figure 9-2: The predicted link volumes for the express transit demand.

9.4.4 The regular demand assignment

We now revert to Scenario 4000, the "First single class assignment," and carry out a similar single-class- generalised-cost assignment with mf10, the regular transit demand. The assignment parameters are as follows:

An auto assignment has already been performed on scenario 4000:
Extra fct. parameter: el1: ul1
..... fixed costs: 0.10000*length
Demand: mf10: Regulr Regular demand
Stopping criteria: iter= 15 rgap= 0.50% ngap= 0.50
Number of iterations: 2 stopped by: ngap

The link volumes arising from this assignment are shown in Figure 9-3. The important feature of the assignment results is the low volume on many of the links, especially those on the periphery of the design area. These links will not support a viable public transport service and so it is desirable to see if there are alternative routes that could be chosen by these travellers.

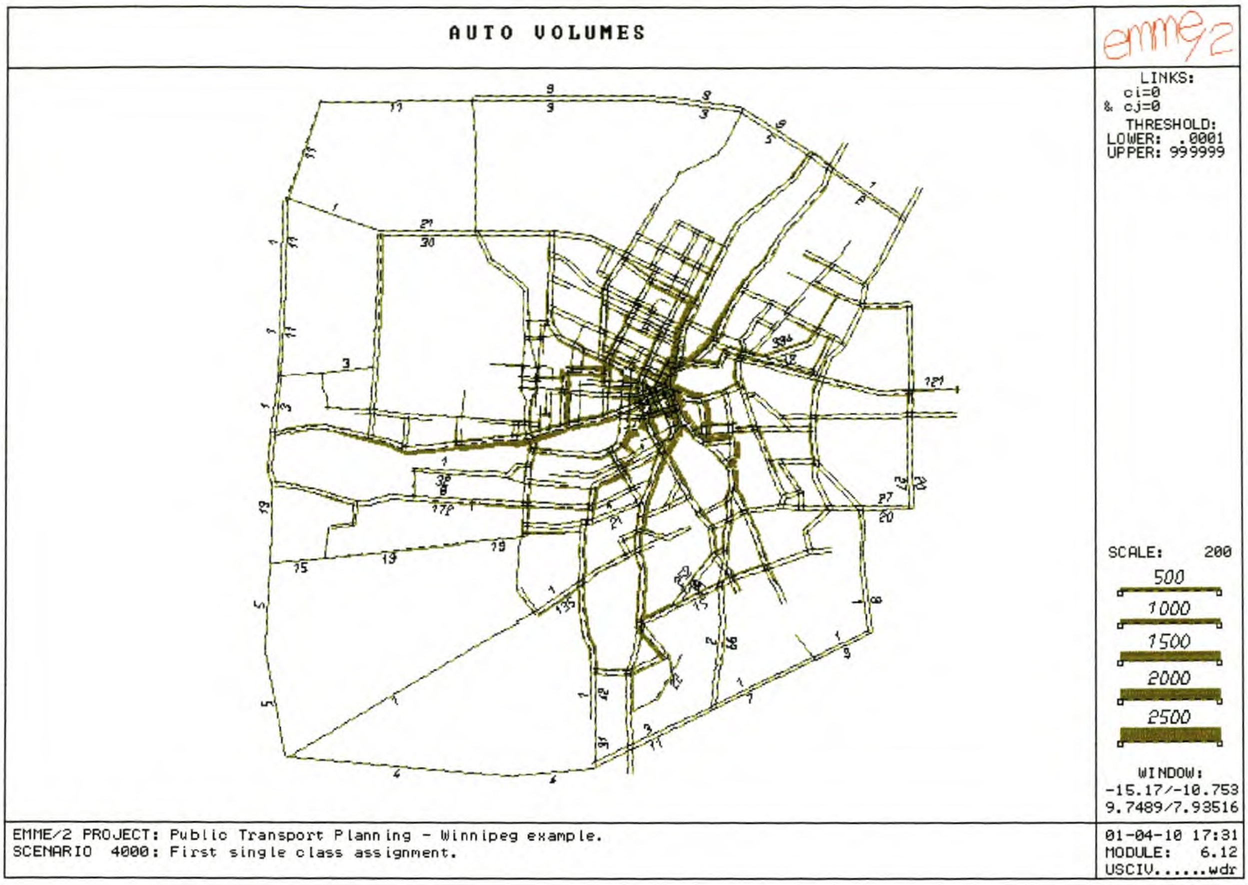


Figure 9-3: The predicted link volumes arising from the single-class, generalised-cost assignment of the regular transit demand.

In order to find those paths that might offer more sustainable public transport routes, we now impose demand penalties on the links with low volume.

9.4.5 The focusing process

The demand penalty is now worked out for the current link volumes. The penalty is not applied to walk-only links or to the centroidal links. This is because these have no impact on the cost of service provision, only on the cost of access to the service. All calculations are thus performed specifying, for the Winnipeg example:

Entry	Meaning
mode=b	Mode = bus
| mode=q	or Mode = car
& ci=0	and ci is not a centroid
& cj=0	and cj is not a centroid

In another example, the mode specifications might include all other motorised modes as well. The order of entry is important. The "& ci, & cj" statement must come at the end. The OR statement always adds elements to the group but the AND statement retains elements only if they qualify. This means that first we select all the mode elements and then limit these to the non-centroidal links. If the centroidal elements are specified first, then the OR mode= will add this mode irrespective of the preceding & statements. See page 3-34 of the Emme/2 User's Manual (INRO 1999.)

The process is iterative and thus to eliminate unnecessary duplication and detail, the process is summarised as follows:

```
Scenario 4000;
Determine ul3 as:
        0.1+0.5*(volau>=12)+0.5*(volaur>=12)
Determine generalised-cost ul2 as:
        0.1*length+(1/ul3)-0.9  Weight = 1.
Copy Scenario 4000 to Scenario 5000.

Scenario 5000;
Run single-class assignment with generalised-cost ul2 having weight of 1.
After assignment determine ul3 as:
        0.1+0.5*(volau>=12)+0.5*(volaur>=12)
        +0.5*(volau>=24)+0.5*(volaur>=24)
Determine generalised-cost ul2 as:
        0.1*length+(2/ul3)-0.9  Weight = 1
Copy Scenario 5000 to Scenario 6000

Scenario 6000;
Run single-class assignment with generalised-cost ul2 having weight of 1.
After assignment determine ul3 as:
        0.1+0.5*(volau>=12)+0.5*(volaur>=12)
        +0.5*(volau>=24)+0.5*(volaur>=24)
        +0.5*(volau>=36)+0.5*(volaur>=36)
Determine generalised-cost ul2 as:
    0.1*length+(3/ul3)-0.9  Weight = 1
Copy Scenario 6000 to Scenario 7000
```

```
Scenario 7000;
Run single-class assignment with generalised-cost ul2 having weight of 1.
After assignment determine ul3 as:
            0.1+0.5*(volau>=12)+0.5*(volaur>=12)
            +0.5*(volau>=24)+0.5*(volaur>=24)
            +0.5*(volau>=36)+0.5*(volaur>=36)
            +0.5*(volau>=48)+0.5*(volaur>=48)
Determine generalised-cost ul2 as:
            0.1*length+(4/ul3)-0.9  Weight = 1
Copy Scenario 7000 to Scenario 8000.

Scenario 8000;
Run single-class assignment with generalised-cost ul2 having weight of 1.
```

This assignment has the effect of penalising all links that have a demand of less than 48 trips per hour, or the equivalent of four vehicle trips per hour of the smallest available public transport vehicle. Further focusing or different step sizes could be used if desired but these suffice for the example. Although not of great importance to the technical process, of some interest in visualising the results, it is useful to modify the display of the last assignment results to show different categories of demand on the network links. This is done as follows:

```
Set colours:
Set Ul3 = 4-((volau>=98).or.(volaur>=98))-((volau>=1000).or.(volaur>=1000))
```

This sets the display colours as follows:

- Where there are >=1000 trips in at least one direction to RED.
- Where there are between 98 and 1000 trips in at least one direction to GREEN.
- Where there are less than 98 trips in either direction to BLUE.

The 98 trip demand is that determined in Chapter 5, Table 5-1 as the change over from taxi to bus. For the example, the 1000 change over point is arbitrary as there are only buses available to carry this demand and the peak demand levels of 2943 are within the carrying capacity of a bus system. In reality, a cost benefit analysis would be necessary to determine suitable change-over values.

The results of the focusing process arising after following these steps is shown in Figure 9-4, which shows the link volumes. As can be seen, this is a significantly different picture from that presented in Figure 9-3, the results of the unfocused single-class assignment of the transit demand.

The entire process can be incorporated in a macro such as the macro Comp.mac given on the compact disc in the folder \Emme2\Macros. This macro deviates slightly from the above description inasmuch as that the scenarios already existed as a result of which it was preferable to manipulate the link attributes only.

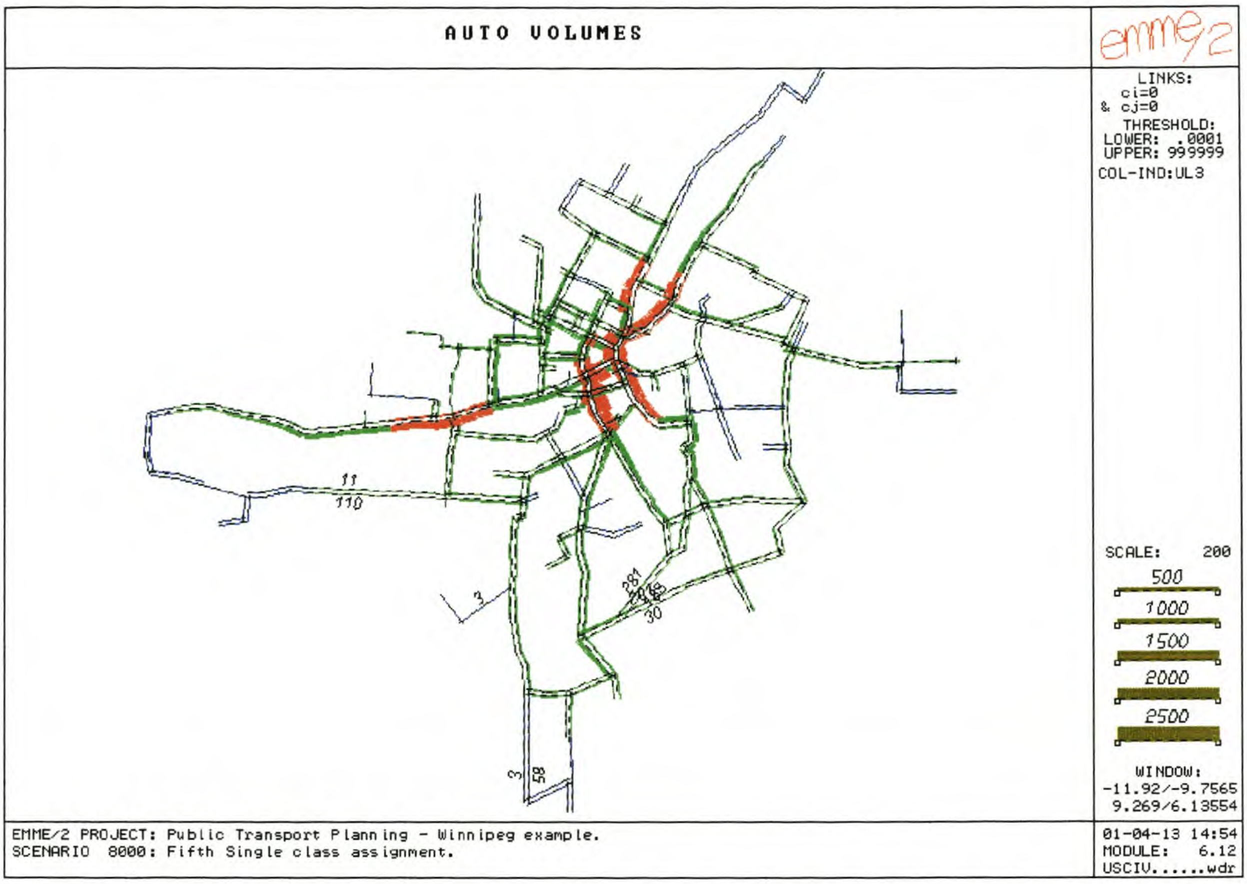


Figure 9-4: Predicted link volumes for transit after 4 steps of focusing and enhancement. The number of trips in at least one direction are denoted by the colours: Red ≥ 1000, Green ≥ 98 and Blue < 98:

9.4.6 Checking the travel times

Once the focusing is complete, it is desirable to check that the focusing process has not had an undue effect on the travel times. This is achieved by creating a new scenario, Scenario 11000 in this case. This is a copy of Scenario 3000 and thus has the original volume delay functions, not the fixed values. We now copy the demand penalty from the last focus assignment, i.e. from

Scenario 8000. This means copying ul2 from the one scenario to the other. We now run a multi-class, generalised-cost assignment with class specific volumes for which two extra attributes, @tlinks and @plinks are created. This assignment uses the full transit demand matrix with the vehicle occupancy value used in the first multi-class assignment. The assignment parameters are as follows:

```
An auto assignment has already been performed on scenario 11000:
Extra fct. parameter: el1:  ul1
Class 1:            Mode: t (AllTransit)
..... fixed costs:    1.00000*ul2
Demand:               mf02: gpqtr0/r  transit demand dpr0000
Vehicle occupancy:   ms01: TrnOcc    Transit occupancy.
..... link volumes:   @tlink  Transit volumes
Class  2:            Mode: q (AuxAuto   )
..... demand:         mf01: wod76d/r  1976 observed auto demand (vehicles)
..... link volumes:   @plink  Private volumes
Stopping criteria:   iter=  15     rgap=  0.50%     ngap=  0.50
Number of iterations:   13          stopped by: ngap
```

The results of this assignment are shown in Figure 9-5. An important point to note is that the volumes are vehicle and not people volumes. There thus appear to be very few transit vehicles.

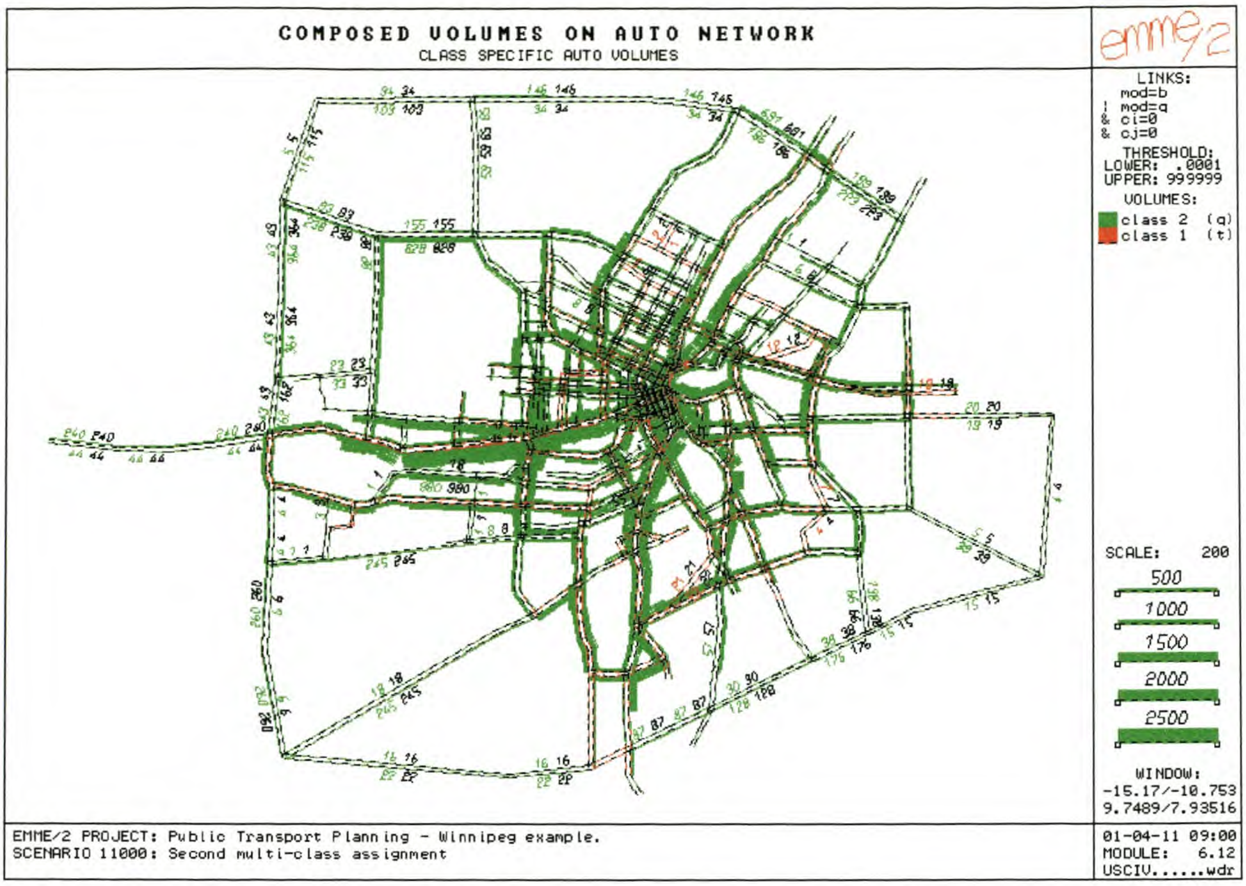
9.5 DATA TRANSFER BETWEEN EMME2/ AND THE DSS DATABASE

In order to run the route extraction program and the resource allocation model, it is necessary to transfer some of the base data and the assignment results from the Emme/2 model to the DSS database. There are other common tables, such as the colour and line pattern codes used by Emme/2. These are used to set up input files for Emme/2 when necessary but are not relevant to the case study and so are not discussed further.

9.5.1 The Emme/2 output process

There are four categories of data that must be transferred from Emme/2 to the DSS Database. These are details of the:

- Modes
- Transit vehicles
- Nodes and Links
- Assignment results



COMPOSED VOLUMES ON AUTO NETWORK
CLASS SPECIFIC AUTO VOLUMES

EMME/2 PROJECT: Public Transport Planning - Winnipeg example.
SCENARIO 11000: Second multi-class assignment

01-04-11 09:00
MODULE: 6.12
USCIV......wdr

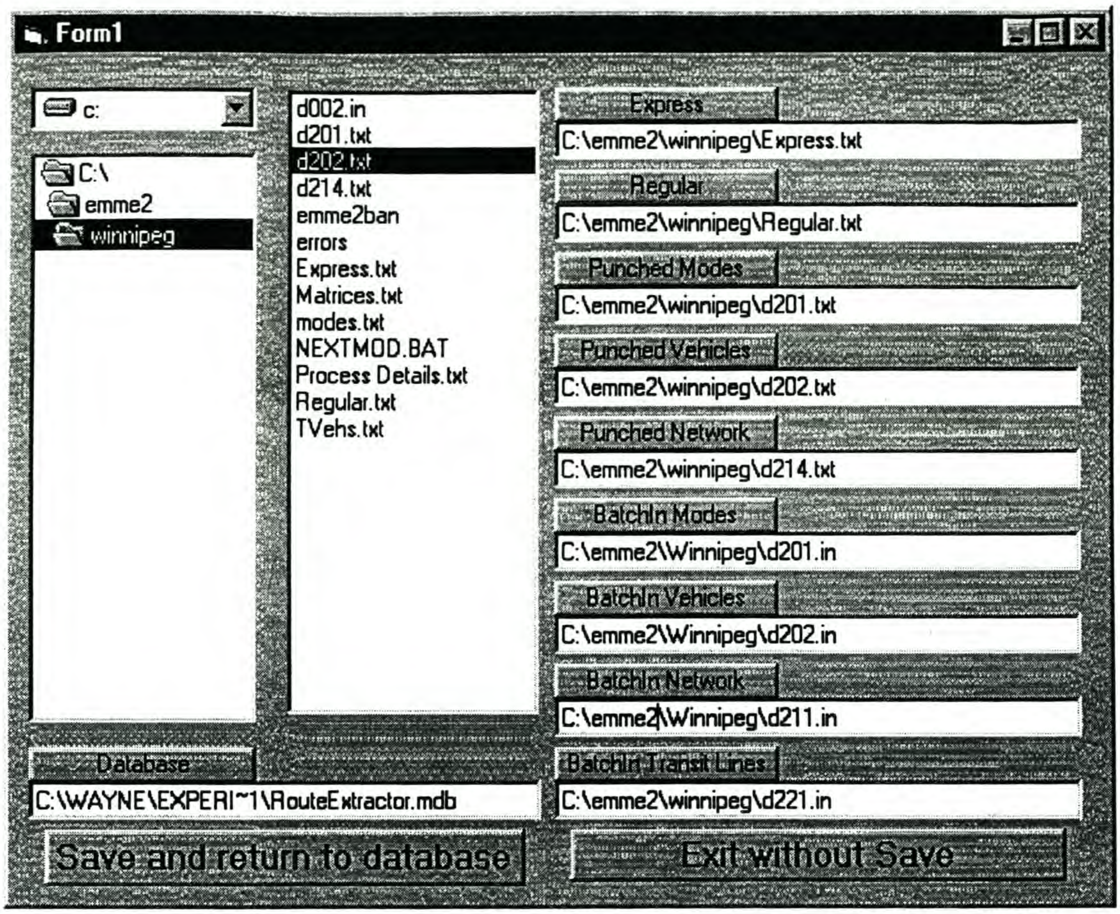
Figure 9-5: Predicted class vehicle-volumes on network after focusing process.

(In this figure, the Class 1, Class 2 and Total volumes are given. When the Class 1 volume is too low, only the Class 2 and Total volumes are given. Care must thus be taken in interpreting the numbers given.)

In each case, the Emme/2 print or punch option is used to create a text file, each suitably named to be readily identified later. For the purpose of the example, the files shall be named for the module except for the assignment output files. Thus, the modes will be output to file 201.txt and the nodes and links, together, are output to 214.txt. The assignment results are output to the files Regular.txt and Express.txt.

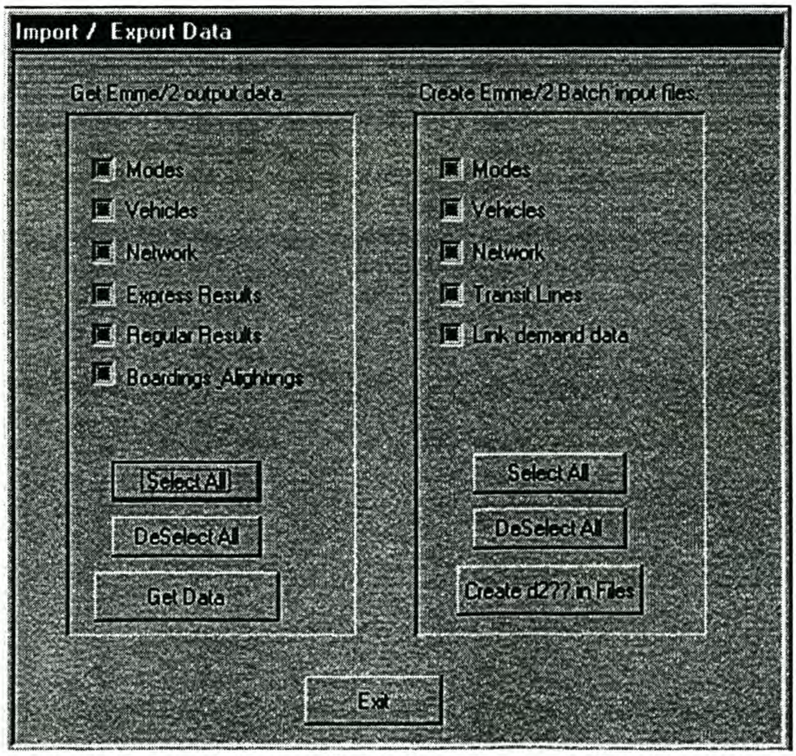
9.5.2 The DSS Database input process

The database has an import module that is able to read the output files created by Emme/2. In theory, it is possible to access the Emme/2 databank directly but this was not considered a worthwhile option. In order to carry out the import, the user must first specify the file paths. This is done via a menu option leading to a form shown in Figure 9-6. Once set for a project, these paths need not be changed or reset as the details are saved in the database. The files to be imported are then selected using the form shown in Figure 9-7. The data is then read from the specified text file into the database.



Express: C:\emme2\winnipeg\Express.txt
Regular: C:\emme2\winnipeg\Regular.txt
Punched Modes: C:\emme2\winnipeg\d201.txt
Punched Vehicles: C:\emme2\winnipeg\d202.txt
Punched Network: C:\emme2\winnipeg\d214.txt
BatchIn Modes: C:\emme2\Winnipeg\d201.in
BatchIn Vehicles: C:\emme2\Winnipeg\d202.in
BatchIn Network: C:\emme2\Winnipeg\d211.in
BatchIn Transit Lines: C:\emme2\winnipeg\d221.in
Database: C:\WAYNE\EXPERI~1\RouteExtractor.mdb

Figure 9-6: Setting the file names and paths used to communicate between the Emme/2 model and the DSS database.



Get Emme/2 output data:
☒ Modes
☒ Vehicles
☒ Network
☒ Express Results
☒ Regular Results
☒ Boardings Alightings

Create Emme/2 Batch input files:
☒ Modes
☒ Vehicles
☒ Network
☒ Transit Lines
☒ Link demand data

Figure 9-7: Import / Export selection form.

During the import process, the link data is tested and marked to indicate one-way or two–way links. The reverse link pointer is added to the data table assuming that the reverse link lies between the same nodes as the forward link. At the same time, the centroidal links are marked as such.

9.6 PREPARING THE DSS DATA

The DSS database supports two main processes, the route extraction and the resource allocation. These require different levels of detail but as far as possible, the requirements overlap. The most important common descriptor is the mode group, road, rail, ferry, etc.

It is a feature of MS Access that it is possible to filter data by form with the forms active in the DSS. The user can thus easily isolate specific data elements requiring more detailed study. The following descriptions are based on ability of the user to make use of this when necessary.

9.6.1 The mode data

As just mentioned for each mode, a mode group must be specified. In the case study, relevant possibilities are:

- All — This covers the "t" mode, which covers all possible transit modes, and pedestrian access.
- Road — This covers the bus and taxi modes.

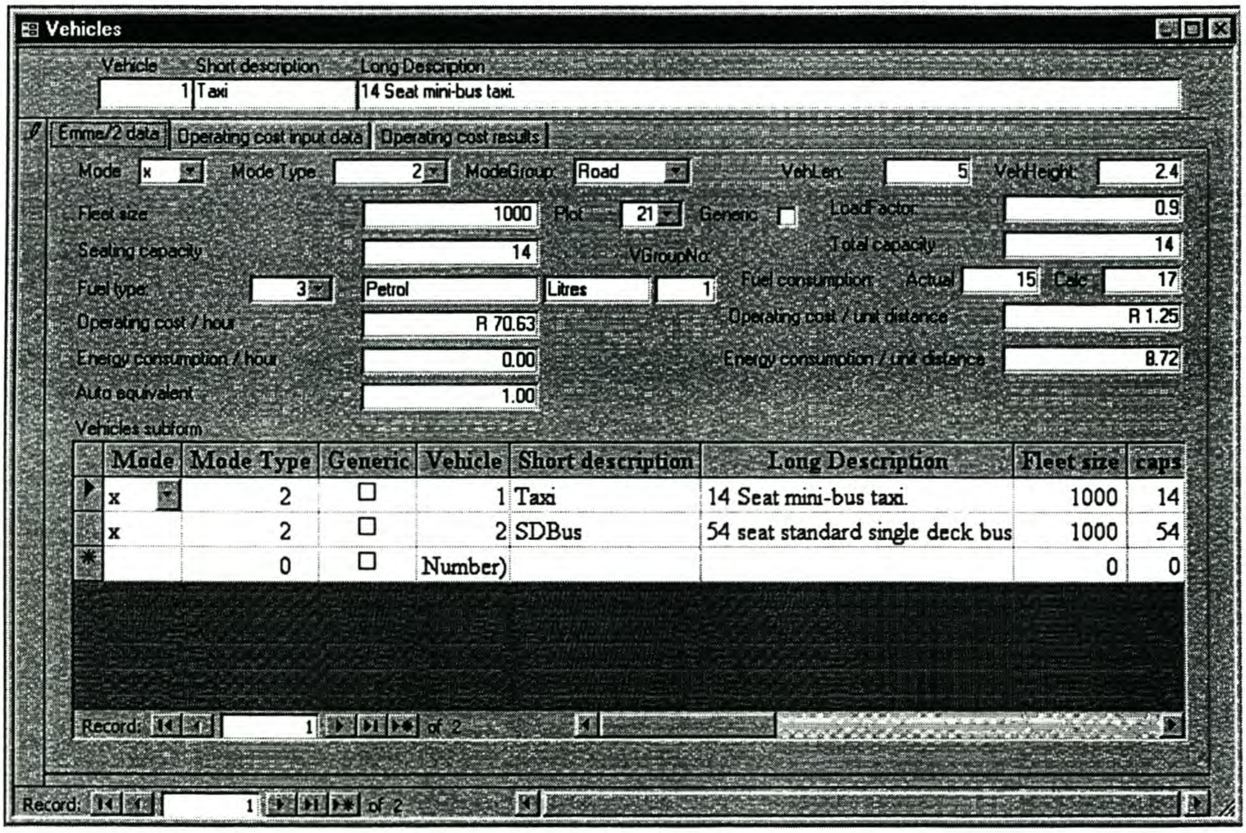
Had there been rail mode in the model, the mode group rail would have been included. Mode groups can be edited and added as necessary. All modes that use road must be specified as such so that the links carrying that mode will be included in the route extraction process. Links that only carry walk type modes will not be included, as they will be in the "All" group.

The planner may also enter information on operating cost and fuel consumption per hour and per kilometre where these are applicable and available. The vehicle data used in resource allocation requires information that is more comprehensive. The transit assignment process will also use the vehicle data so the mode data need not be complete in this respect.

9.6.2 The vehicle data

The vehicle data refers to the public transport vehicles being used in the design process. If there were vehicles specified in the Emme/2 model but these are not appropriate, the database may be used to delete or edit the data and new vehicles may be added. The necessary information will be passed back to Emme/2 later. The data form for the transit vehicles is in three pages and it is necessary to enter all the data required by Emme/2, the Vehicle Cost Schedule shown in Table 7-1 in Chapter 7. This data is the basis of the resource allocation process as well as any exercise in evaluation of pollution generation and energy consumption using Emme/2. Consequently, a reasonable degree of accuracy is required.

The data forms access the vehicle cost spreadsheet and use this to calculate the operating costs of the vehicles if not provided by the user. There is also a built in calculator to allow quick re-estimation of the operating costs given changed mileage or operating hours. The first of the three screen pages of this data form is shown in Figure 9-8.



Vehicle: 1
Short description: Taxi
Long Description: 14 Seat mini-bus taxi.

Mode: x
Mode Type: 2
ModeGroup: Road
VehLen: 5
VehHeight: 2.4
Fleet size: 1000
Plot: 21
Generic: ☐
LoadFactor: 0.9
Seating capacity: 14
VGroupNo:
Total capacity: 14
Fuel type: 3 Petrol Litres 1
Fuel consumption: Actual 15 Calc 17
Operating cost / hour: R 70.63
Operating cost / unit distance: R 1.25
Energy consumption / hour: 0.00
Energy consumption / unit distance: 8.72
Auto equivalent: 1.00

Vehicles subform

Mode	Mode Type	Generic	Vehicle	Short description	Long Description	Fleet size	caps
x	2	☐	1	Taxi	14 Seat mini-bus taxi.	1000	14
x	2	☐	2	SDBus	54 seat standard single deck bus	1000	54
	0	☐	Number)			0	0

Record: 1 of 2

Record: 1 of 2

Figure 9-8: The first of three screen pages of the vehicle data form in the DSS. This page contains the Emme/2 data requirements and an overview of the vehicles available to the system.

9.6.3 The network data

The network data includes information on the nodes and the links. The only modification that may be required to the node data is the addition of a node name. This is usually only required, if at all, after the route design process is complete although it may help to do so before hand to simplify evaluation of the route extraction output. Node names have not been given in the case study example.

The link data can also be modified to reflect street names. This is optional and serves the same purpose of making the results easier to read. However, an important aspect that needs evaluation early on, is the issue of one-way streets. In order to facilitate this, the assignment results must have been imported. If this has been done, a menu option gives access to a form for viewing and editing the one-way link data. The case study has 239 such links. Of these 15 are centroidal links and another 158 carry no demand although some are the pair of other one-way links which do carry demand. Thus, at least 66 links require modification to indicate the reverse path to be followed in designing a route including these links. The macro "Setul1" in the DSS can be run to modify the link data. This can then be exported via the import / export menu option and modified using any text editor to create an Emme/2 batch input file to modify the links. This has been done and the resulting Emme/2 graphic is shown in Figure 9-9.

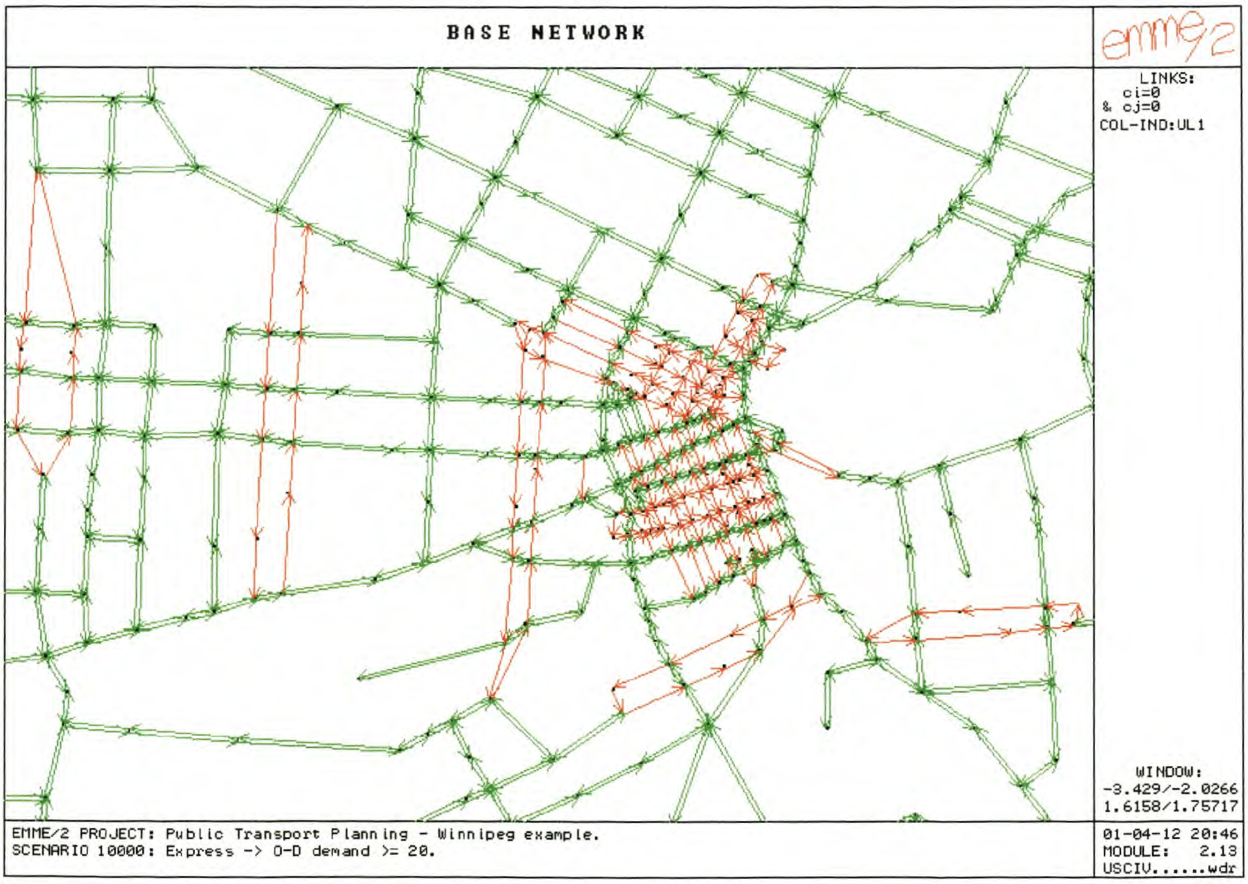
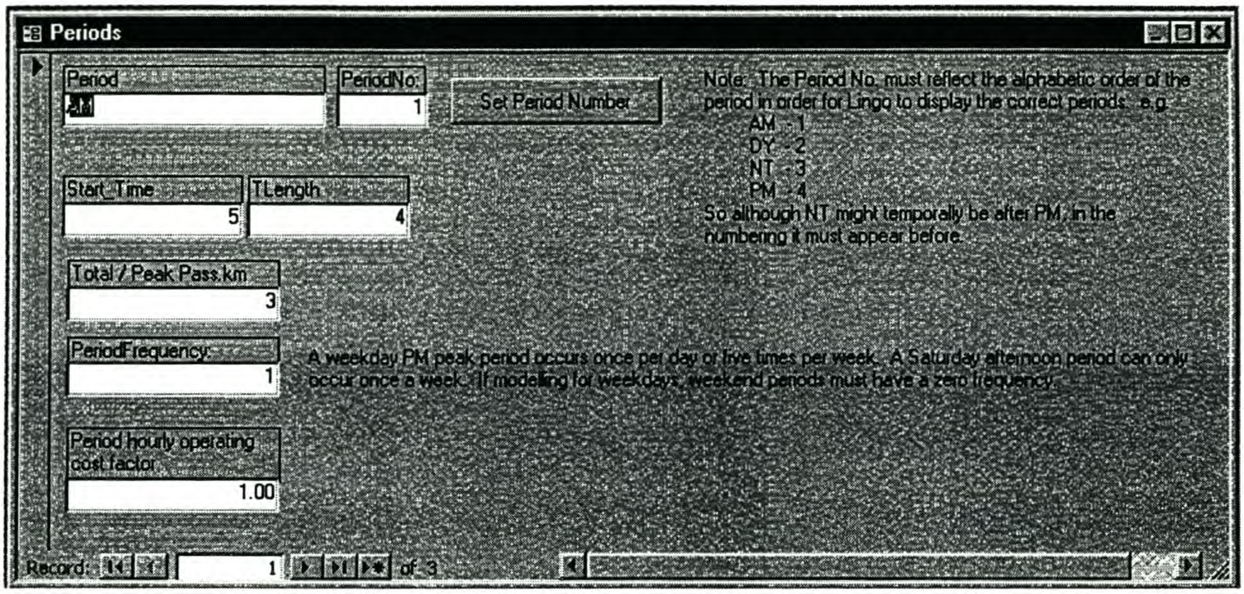


Figure 9-9: Graphical representation of one-way links in the Winnipeg network.

The DSS database does not yet include allowance for a many-to-one relationship for one-way links. Such allowance is possible but requires extensive additional coding not considered relevant to demonstration of the overall principles presented in this dissertation. The one-way links are thus ignored for the moment and it is assumed that transit lines can travel both ways on all links. This will lead to some inaccuracies in the estimates of passenger-kilometres in the case study example.

9.6.4 The operating periods

In order to enable modelling of different operating periods, the periods must be specified. This is carried out via a menu option and the form shown in Figure 9-10.



Period: AM
PeriodNo: 1
Start_Time: 5
TLength: 4
Total / Peak Pass.km: 3
PeriodFrequency: 1
Period hourly operating cost factor: 1.00

Note: The Period No. must reflect the alphabetic order of the period in order for Lingo to display the correct periods. e.g.
AM - 1
DY - 2
NT - 3
PM - 4
So although NT might temporally be after PM, in the numbering it must appear before.

A weekday PM peak period occurs once per day or five times per week. A Saturday afternoon period can only occur once a week. If modelling for weekdays, weekend periods must have a zero frequency.

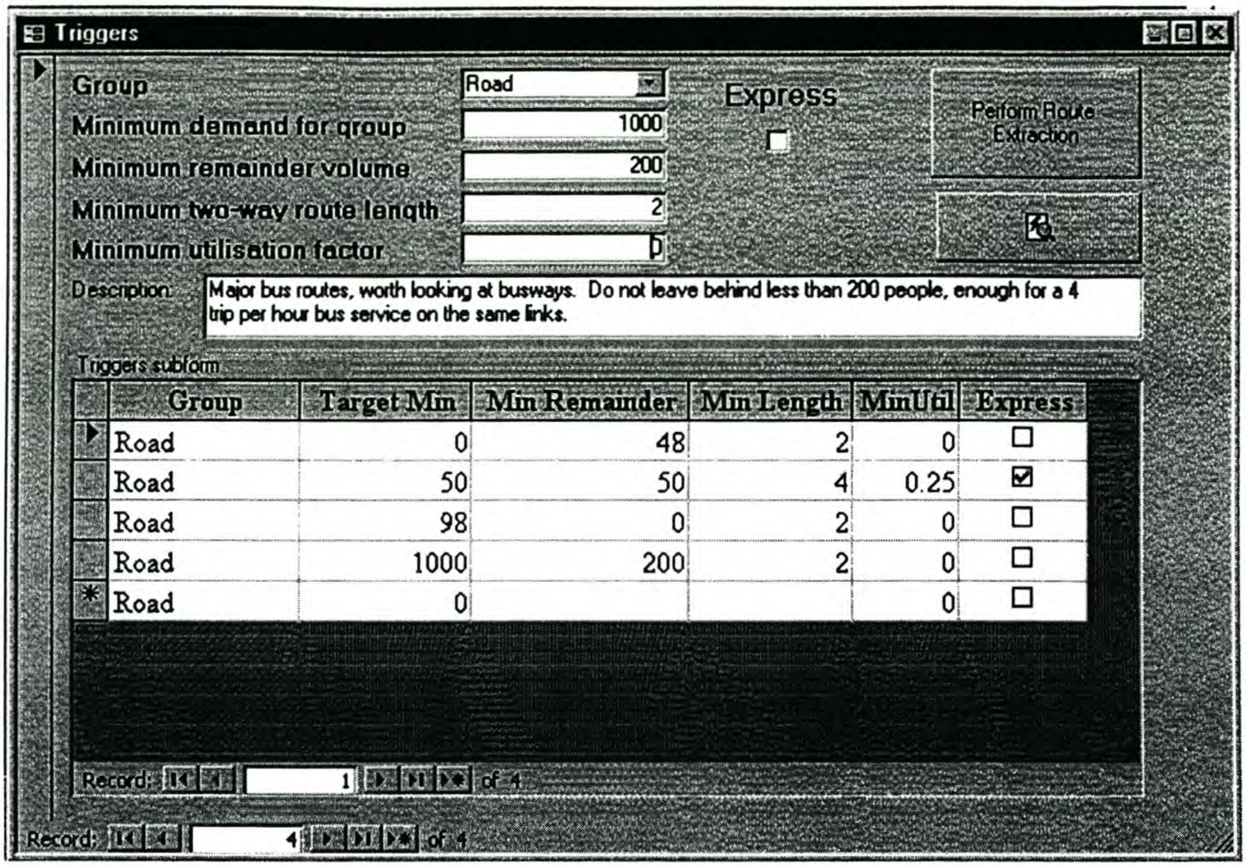
Figure 9-10: The DSS form for adding and editing the operating periods.

The period data is used to estimate the passenger-kilometres and fare revenue given only the design hour demand levels. It is also used as a control mechanism so that the route data for a single period can be deleted and replaced without affecting the data for other periods. In this respect, the database carries only two working data files for the assignment results, one for "Express" and one for "Regular" demand. This means that for each operating period, once the route extraction process is complete, the table containing the assignment data must be copied and saved under a new name. When running the route extraction process, the program asks the user to specify the operating period from which the assignment data is derived and includes this in the route identifier.

9.6.5 Route extraction variables

The route extraction process utilises demand categories to split routes up to best suit the available vehicle types and the possibility of right-of-way operations. The categories used in the case study are shown in Figure 9-11. These cater for:

- An express bus service.
- A taxi-based feeder network.
- A regular bus service.
- A high volume, potential bus lane, bus service.



Group: Road
Minimum demand for group: 1000
Minimum remainder volume: 200
Minimum two-way route length: 2
Minimum utilisation factor: 0
Express: ☐
Description: Major bus routes, worth looking at busways. Do not leave behind less than 200 people, enough for a 4 trip per hour bus service on the same links.

Group	Target Min	Min Remainder	Min Length	MinUtil	Express
Road	0	48	2	0	☐
Road	50	50	4	0.25	☑
Road	98	0	2	0	☐
Road	1000	200	2	0	☐
Road	0			0	☐

Figure 9-11: The route extraction categories.

One remaining category has been implemented in the example to absorb all outstanding trips so that they can be analysed. This category simply sets all the extraction parameters to zero. A route will thus be declared for one trip or for one hundred metres but only after all the conventional category extraction is complete.

9.7 THE ROUTE EXTRACTION PROCESS

From the user perspective, the route extraction process itself requires no action other than to set it in motion. This is done by selecting the operating period and activating the process. Thereafter it is a matter of waiting for the process to complete. The time taken depends on the computer being used. For the Winnipeg case study, a 530 MHz Pentium with 128 MB of ram and running Windows NT requires about 5 minutes. Owing to a weakness in MS Access, 128 MB Ram is required to run the example model. This requirement can be overcome by using a Visual Basic interface instead of the MS Access interface used in the demonstration version to facilitate portability of the programme code.

The results of the process are shown in APPENDIX J. Due to the limitations of the demonstration code, there is at least one anomaly. Route Number 85 is extracted as one of the "outstanding trip" routes but meets all the criteria for an acceptable route. This is believed to be due to the one-way link issue as the end node of this route is connected to two one-way links. There may be other similar anomalies in the extraction results arising from the same cause. For the purpose of demonstration, these are not considered critical to the overall process especially since the routes thus obtained are not lost to the design process.

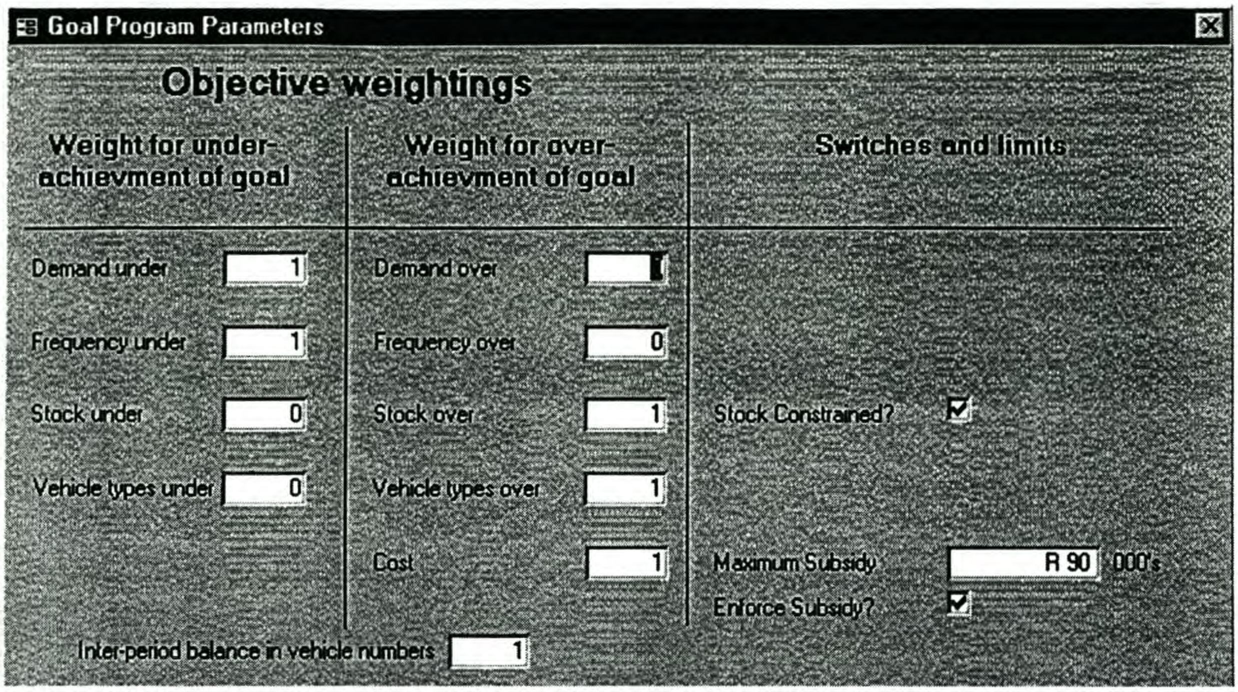
9.8 THE RESOURCE ALLOCATION PROCESS

In reaching this stage of the modelling process, much of the data entry will already have been completed. However, the results of the route extraction process are incomplete in some respects and must be modified. In particular, some modifications to the route data are required and the vehicle cost data must be entered if this has not already been done.

The "Resource Allocation Menu" provides access to the Route data, the Vehicle data, and thus to the vehicle cost model, and to the input form for the resource allocation weightings, switches and subsidy limitations. The data access forms are self-explanatory and the contents have been discussed at some length in preceding chapters. The following points should be noted however:

- For the routes, the actual fare charged on the route, policy frequency, minimum terminal time, and vehicle restrictions must be entered for each route, using either a global update of the data or on a route by route basis. Any other route modifications, such as route node-sequence alterations, will be carried out at this stage as well.
- The vehicle cost and operating data were described in the chapter on Fleet Costs. If it has not already been done, the vehicle costs must be determined as accurately as possible to which end the spreadsheet model is provided as an aid. The planner may provide either the detailed data necessary for the calculations or the total per hour and per kilometre costs according to what is available. The first page of the vehicle data must be provided as it includes the vehicle information used by Emme/2 and the Lingo model. If only the summary data is provided, the vehicle cost calculator must not be invoked for the vehicle as this will result in the correct data being over-ridden or the occurrence of a program error.
- The goal weights must be specified and the maximum subsidy entered and the switches set. A form for this is shown in Figure 9-12. This form is applicable to the demonstration example but requires modification for commercial implementation of the model.

In the case study, there is a case where the technical maximum frequency specified is inadequate to meet the demand, given the vehicle types available. The upper bound number of trips thus has to be raised or an alternative vehicle type or transport mode needs to be introduced.



Demand under 1
Frequency under 1
Stock under 0
Vehicle types under 0
Demand over 1
Frequency over 0
Stock over 1
Vehicle types over 1
Cost 1
Stock Constrained? ☑
Maximum Subsidy R 90 000's
Enforce Subsidy? ☑
Inter-period balance in vehicle numbers 1

Figure 9-12: Resource allocation objective weights and other parameter settings.

Once these entries, each accessed via a menu option, have been made, the planner can engage the resource allocation process itself, also via a menu option. This option leads to a form where the planner can select from a number of different Lingo models. The DSS contains two different versions of the resource allocation model and a number of other subsidiary models. The Lingo package will be activated when a model is selected via the form. The user can then edit and run the model from within Lingo. The data will be retrieved from and returned to the DSS database.

One important note here is that the DSS database must be registered with the ODBC (Open Database Connectivity) manager under the name "BatchData" in order for the Lingo model to access the database. This can be changed but must be changed in the Lingo model and the ODBC manager.

For the case study, the Lingo license is inadequate to allow the entire Winnipeg model to be run in one go. Initially, the data was split into three sections to accommodate this problem. In carrying out the case study, the MIP solution of two of the three data sets was relatively easy with the Lingo 6.0 package. The third set could however not be solved with the given parameters with Lingo 6.0 but was readily solved using a translation of the model using GAMS (Kalvelagen 2001.) (GAMS is a modelling language, that interfaces with many state-of-the-art LP, MIP and NLP solvers. GAMS Development Corp, Washington DC, USA.) The GAMS solution file is contained on the CD as :\Lingo\Winnipeg\Lingo1.lst. This was done for the author by Erwin Kalvelagen of GAMS, using CPLEX and XPRESS, both of which solved the problem in a matter of seconds.

The problem was "solved" by Lindo Systems using a beta version of Lingo 7.0 in about 90 seconds but the results contained serious flaws and were unusable. These gave rise to some modifications of the model. The author was subsequently given a temporary copy of the Lingo 7.0 beta version, which has been used for the rest of the case study although still with considerable difficulties. These problems meant that the data was split into four sections instead of three in order to produce a solution to the problem posed.

The lesson from this is that in implementing the DSS in a commercial environment, the selection of the solver software must be undertaken with considerable care. From the author's perspective however, it was at least demonstrated that the basic model formulation was sufficiently sound to enable translation and solution. Some modifications are of course desirable. For example, the Lingo model is used to determine a number of "accounting" variables, which play no role in the actual MIP. These calculations should be made in the DSS database to improve overall DSS performance although this may involve some quite extensive additional coding. Such changes would be applied in a commercial application.

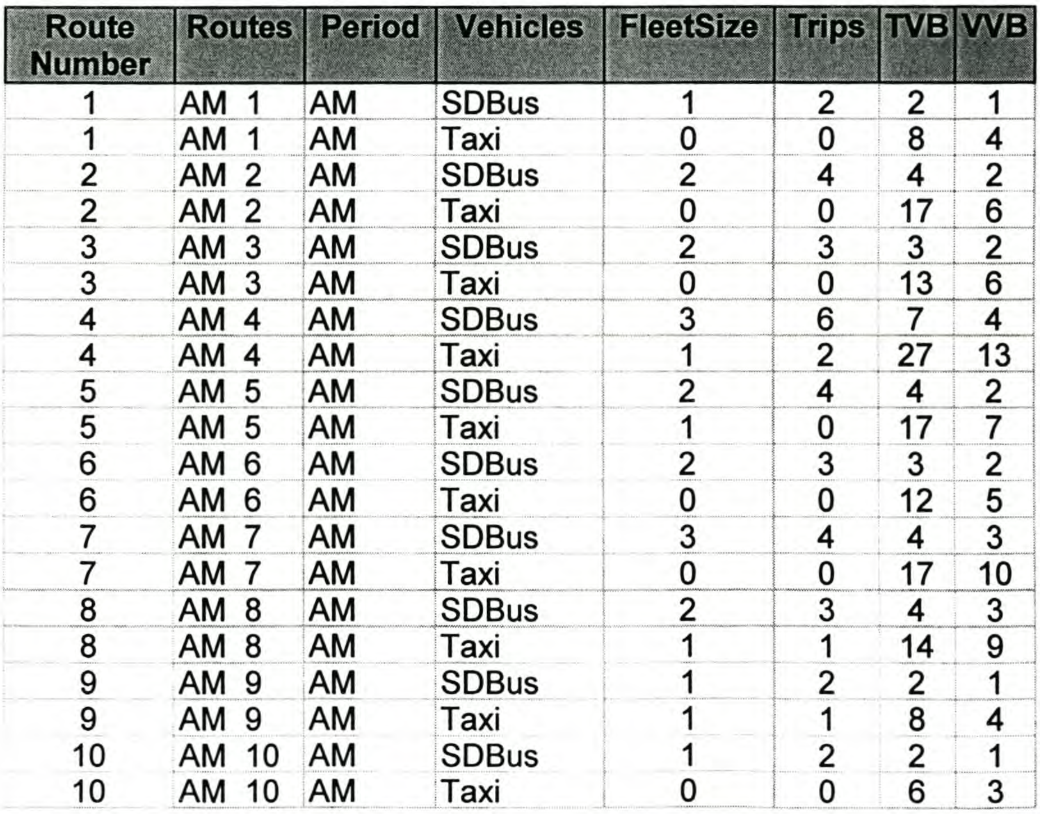
Carrying out the allocation in steps may mean that the result is not the optimum in a constrained environment but will not influence the overall results if the fleet and subsidy are not limited. The routes have been split up to reflect the express routes and then the remaining routes in three groups. This was achieved by setting parameters in the "QRoutes" and the "RouteToLines" queries used to provide the data to the Lingo model. The allocation process is thus carried out four times, the results being saved separately each time in Lingo format. This splitting of the allocation process is not visible in the DSS database where the results are given on a route basis.

As mentioned in Chapter 6, discussing the resource allocation model, it is preferable to run the allocation process as a non-integer or Linear Program (LP) model first. The integer and binary variable declaration statements must thus be blocked out by preceding them with an exclamation (!) mark. These lines of code are clearly marked and grouped together. The model is then run. In the case of the express routes where there are ten routes and two vehicle types, the allocation process takes around 60 seconds including the model generation phase on a 133MHz computer with 32-MB ram.

The case study data is such as to reasonably ensure the basic criteria of meeting demand and satisfying the minimum service frequency within the total subsidy allowance. The result is that the allocation results provide the cheapest assignment of vehicles within these parameters. When the model is run in the LP form, the objective value gives an estimate of the lower bound net cost of operating the system for the design period, in this case, the AM peak period which is four hours long. The number of vehicles and vehicle trips will be seen to be real rather than integer values and could thus not be implemented in practice. The results do however provide the planner with a guideline for the mixed integer problem (MIP) which is to be solved.

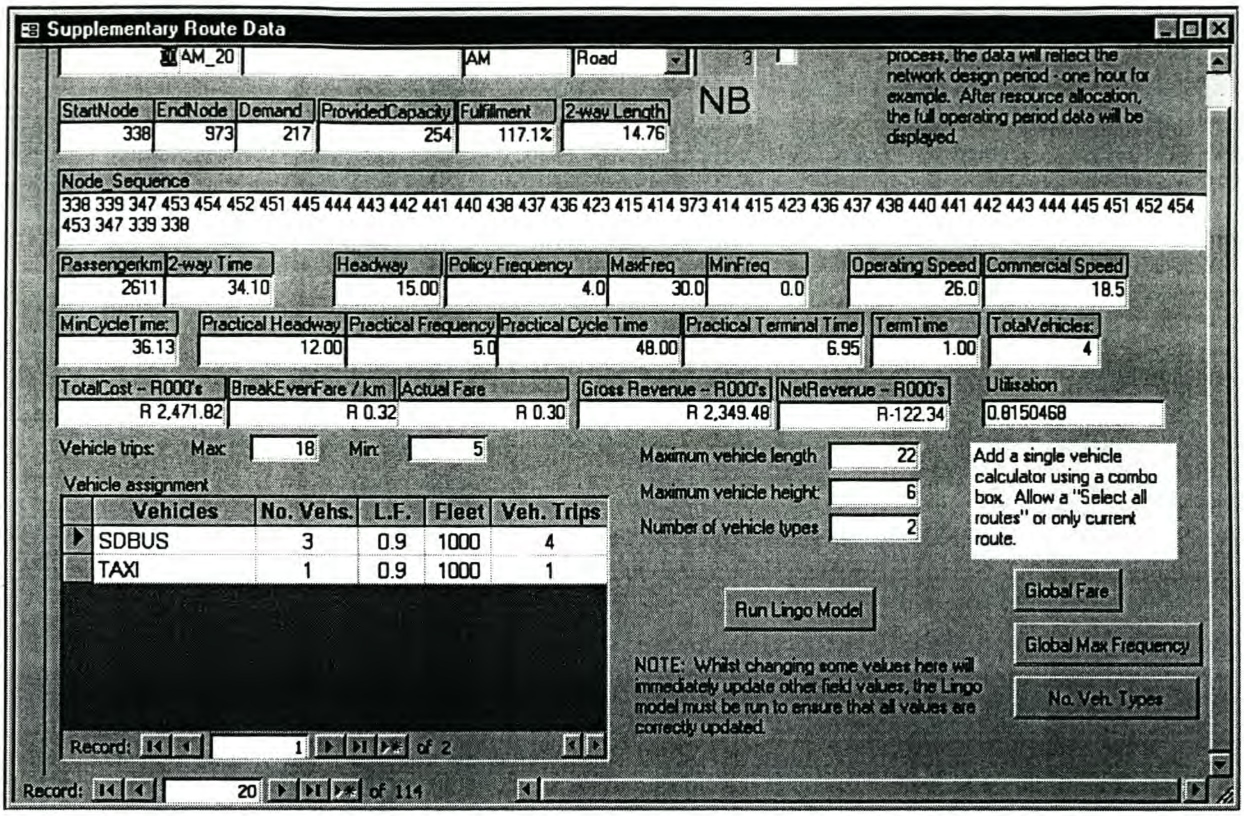
The allocation process results from the three sections have been recombined to allow proper display in the DSS. The allocation results are returned to the DSS in three tables:

- Lines The number of vehicles and vehicle trips assigned to each route for each vehicle type available and operating period as shown in Table 9-1.
- QRoutes All route based information for the design period as shown in Figure **9-13**.
- NetworkData The system costs and revenues for the design period as depicted in Figure 9-14.



Route Number	Routes	Period	Vehicles	FleetSize	Trips	TVB	VVB
1	AM 1	AM	SDBus	1	2	2	1
1	AM 1	AM	Taxi	0	0	8	4
2	AM 2	AM	SDBus	2	4	4	2
2	AM 2	AM	Taxi	0	0	17	6
3	AM 3	AM	SDBus	2	3	3	2
3	AM 3	AM	Taxi	0	0	13	6
4	AM 4	AM	SDBus	3	6	7	4
4	AM 4	AM	Taxi	1	2	27	13
5	AM 5	AM	SDBus	2	4	4	2
5	AM 5	AM	Taxi	1	0	17	7
6	AM 6	AM	SDBus	2	3	3	2
6	AM 6	AM	Taxi	0	0	12	5
7	AM 7	AM	SDBus	3	4	4	3
7	AM 7	AM	Taxi	0	0	17	10
8	AM 8	AM	SDBus	2	3	4	3
8	AM 8	AM	Taxi	1	1	14	9
9	AM 9	AM	SDBus	1	2	2	1
9	AM 9	AM	Taxi	1	1	8	4
10	AM 10	AM	SDBus	1	2	2	1
10	AM 10	AM	Taxi	0	0	6	3

Table 9-1: An extract of the allocation results, in the Lines Table, giving the number of vehicles and vehicle trips for each vehicle type on each route in the network for each operating period.



AM_20 | AM | Road | 3

NB

process, the data will reflect the network design period - one hour for example. After resource allocation, the full operating period data will be displayed.

StartNode	EndNode	Demand	ProvidedCapacity	Fulfilment	2-way Length
338	973	217	254	117.1%	14.76

Node_Sequence
338 339 347 453 454 452 451 445 444 443 442 441 440 438 437 436 423 415 414 973 414 415 423 436 437 438 440 441 442 443 444 445 451 452 454 453 347 339 338

Passengerkm	2-way Time	Headway	Policy Frequency	MaxFreq	MinFreq	Operating Speed	Commercial Speed
2611	34.10	15.00	4.0	30.0	0.0	26.0	18.5

MinCycleTime:	Practical Headway	Practical Frequency	Practical Cycle Time	Practical Terminal Time	TermTime	TotalVehicles:
36.13	12.00	5.0	48.00	6.95	1.00	4

TotalCost - R000's	BreakEvenFare / km	Actual Fare	Gross Revenue - R000's	NetRevenue - R000's	Utilisation
R 2,471.82	R 0.32	R 0.30	R 2,349.48	R-122.34	0.8150468

Vehicle trips: Max: 18 Min: 5

Vehicle assignment

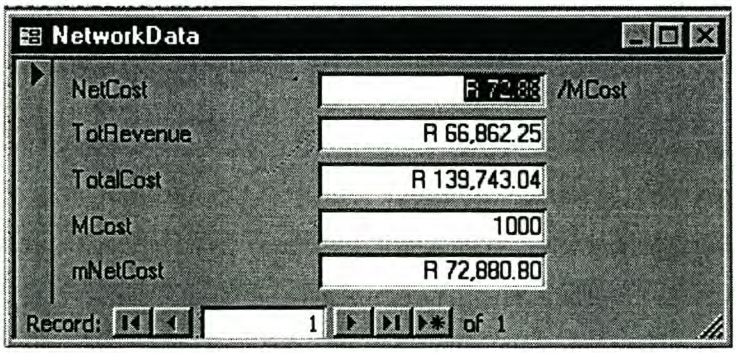
Vehicles	No. Vehs.	L.F.	Fleet	Veh. Trips
SDBUS	3	0.9	1000	4
TAXI	1	0.9	1000	1

Maximum vehicle length: 22
Maximum vehicle height: 6
Number of vehicle types: 2

Add a single vehicle calculator using a combo box. Allow a "Select all routes" or only current route.

NOTE: Whilst changing some values here will immediately update other field values, the Lingo model must be run to ensure that all values are correctly updated.

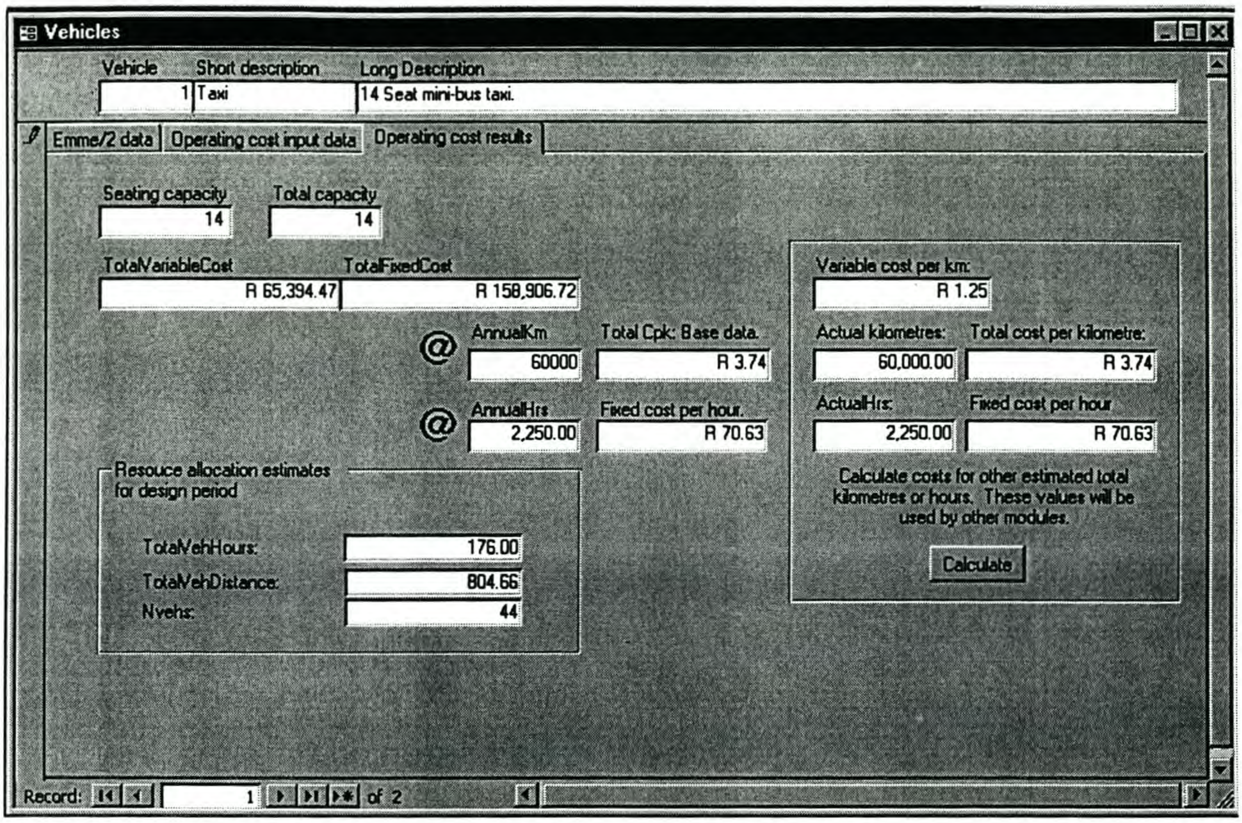
Figure 9-13: The results for a Route after the allocation process. Note the inclusion of the number of vehicles, vehicle types and trips in the subform.



NetCost: R 72.88 /MCost
TotRevenue: R 66,862.25
TotalCost: R 139,743.04
MCost: 1000
mNetCost: R 72,880.80

Figure 9-14: The summary of the costs for the system after the allocation process.

At this stage, it would strictly speaking be desirable to re-evaluate the vehicle operating costs based on the total operating hours and mileage determined by the Lingo model. The model should then be re-run using the revised cost data and so on until a stable condition is achieved. Given that we only have one operating period, all vehicles used are assumed to be employed for the length of the one period as per the allocation model specification. The average vehicle mileage for each vehicle type can be determined for the period and thus also for any number of periods in a year but is not meaningful. The process is thus not carried out in the case study example. The information is however presented in the vehicle data form of the DSS although at this stage of the DSS development, the number of vehicles of each type being used is entered manually from a separate query. An example is shown in Figure 9-15.



Vehicle: 1
Short description: Taxi
Long Description: 14 Seat mini-bus taxi.

Seating capacity: 14
Total capacity: 14
TotalVariableCost: R 65,394.47
TotalFixedCost: R 158,906.72
AnnualKm: 60000
Total Cpk: Base data: R 3.74
AnnualHrs: 2,250.00
Fixed cost per hour: R 70.63

Resouce allocation estimates for design period
TotalVehHours: 176.00
TotalVehDistance: 804.66
Nvehs: 44

Variable cost per km: R 1.25
Actual kilometres: 60,000.00
Total cost per kilometre: R 3.74
ActualHrs: 2,250.00
Fixed cost per hour: R 70.63

Calculate costs for other estimated total kilometres or hours. These values will be used by other modules.

Record: 1 of 2

Figure 9-15: An example of the third page of Vehicle data form. The important element is the "Resource allocation estimates for the design period."

Where there are binding restrictions on the number of vehicles available or some similar restriction forcing the choice of certain vehicles, this process may have little overall impact on the result other than on the operating cost. There are also limitations in the process given the use of average values. A non-linear solver could possibly solve this problem but will naturally impose other burdens. Nevertheless, some revised estimate of the vehicle costs is desirable to improve accuracy. When the MIP solver software is able to cope with the problem adequately, this should not be a major problem.

At this juncture, the system design is ready for evaluation using the network modelling package again. This evaluation may or may not lead to a variety of alterations but serves the purpose of providing boarding and alighting information for each active node in the system.

9.9 TESTING THE LINES WITH EMME/2

It will be recalled that it was necessary to modify the Emme/2 network model link mode definitions to carry out the focusing process. In the case of the Winnipeg model, an additional mode change is required in order to carry out a transit assignment in terms of the overall design philosophy. The base model allows public transport only on links declared as carrying the "b" mode. The SLM philosophy requires that public transport should be allowed access to all links except where physical restrictions prevent it. These restrictions must be specified at the beginning of the process.

However, many links in the model are specified as carrying motorised road transport but do not allow public transport. These links must be modified to allow public transport. This is achieved by defining a new mode, "x," which can access all road links and that represents all road based public transport. All links allowing the "b" or "q" modes, the road based public and private transport modes, are modified to allow the "x" mode. All road based public transport vehicles are defined as being of this mode. It may later be desirable to revert to the separate mode definitions, to distinguish between bus and minibus for example.

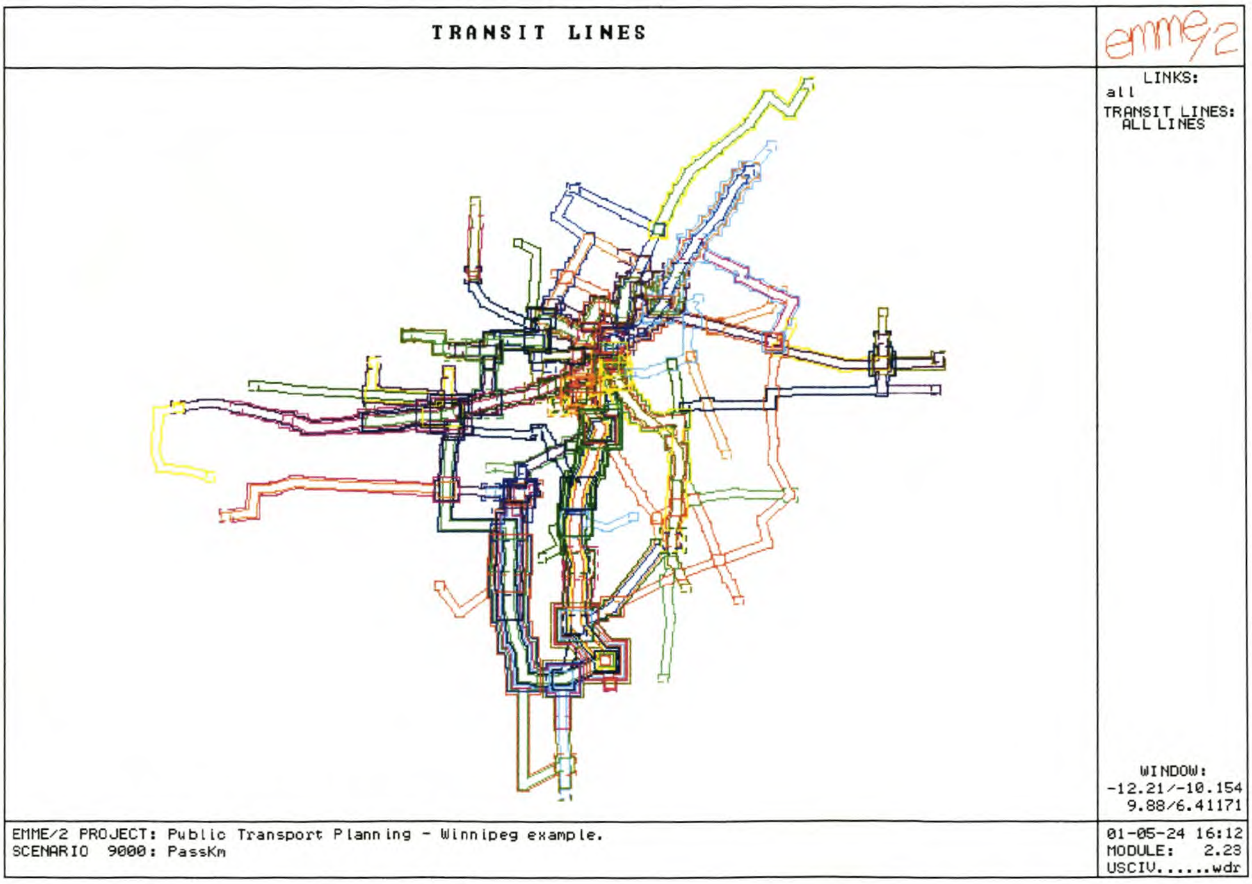
As mentioned previously, the problem of one-way links has not yet been fully resolved in the route extraction code and thus, since several lines make use of one-way links, some mechanism is required in the demonstration model to overcome this limitation. This has been done by the simple expedient of defining a single lane return link for each one-way element.

The next step in the testing process is to create the batch input file for transit lines. This is a menu option in the DSS and once the route specifications are considered acceptable, selection of the option generates the file named in the "Import/Export Filenames and Paths" menu option of the Import/Export menu. In the case study, the file generated is named "d221.in" in accordance with the Emme/2 standard. When this file is created, the export process tests each node in each route path and marks it according to whether or not the line is expected to stop there. The planner may wish to modify these stop markers and can do so, either in the node table of the DSS or in the Emme/2 batch input file. The first line specification in the example file is shown in Figure 9-16. In this example, the routes have been specified as two-way although Emme/2 recommends that they be specified as two, one-way routes. This can be readily implemented should it be desired.

Once the routes have been loaded into Emme/2 using module 2.21, a graphic of the routes can be viewed and the transit assignment can be performed. Figure 9-17 shows graphic representation of the transit lines in Emme/2

```
t lines init
a ' 2AM1' x 2  30  31.19 '2AM1' 0  0  0
 path=no dwt=.17 ttf=0 181 180 tdwt=#0.0 179 tdwt=#0.0 178 177 tdwt=#0.0
 176 tdwt=#0.0 175 tdwt=#0.0 174 173 tdwt=#0.0 172 171 170 tdwt=#0.0 169
 tdwt=#0.0 168 167 tdwt=#0.0 166 tdwt=#0.0 165 tdwt=#0.0 1055 tdwt=#0.0
 1059 tdwt=#0.0 1051 1050 tdwt=#0.0 1047 tdwt=#0.0 1046 1045 1044
 tdwt=#0.0 1043 tdwt=#0.0 1042 1025 tdwt=#0.0 1021 1005 981 lay=4 1005
 1021 1025 tdwt=#0.0 1042 1043 tdwt=#0.0 1044 tdwt=#0.0 1045 1046 1047
 tdwt=#0.0 1050 tdwt=#0.0 1051 1059 tdwt=#0.0 1055 tdwt=#0.0 165 tdwt=#0.0
 166 tdwt=#0.0 167 tdwt=#0.0 168 169 tdwt=#0.0 170 tdwt=#0.0 171 172 173
 tdwt=#0.0 174 175 tdwt=#0.0 176 tdwt=#0.0 177 tdwt=#0.0 178 179 tdwt=#0.0
 180 tdwt=#0.0 181 lay=4
a ' 2AM2' x 2  15  32.19 '2AM2' 0  0  0
```

Figure 9-16: An extract from the beginning of the transit line specification file for entering the transit lines into Emme/2.



LINKS:
all
TRANSIT LINES:
ALL LINES

WINDOW:
-12.21/-10.154
9.88/6.41171

EMME/2 PROJECT: Public Transport Planning - Winnipeg example.
SCENARIO 9000: PassKm

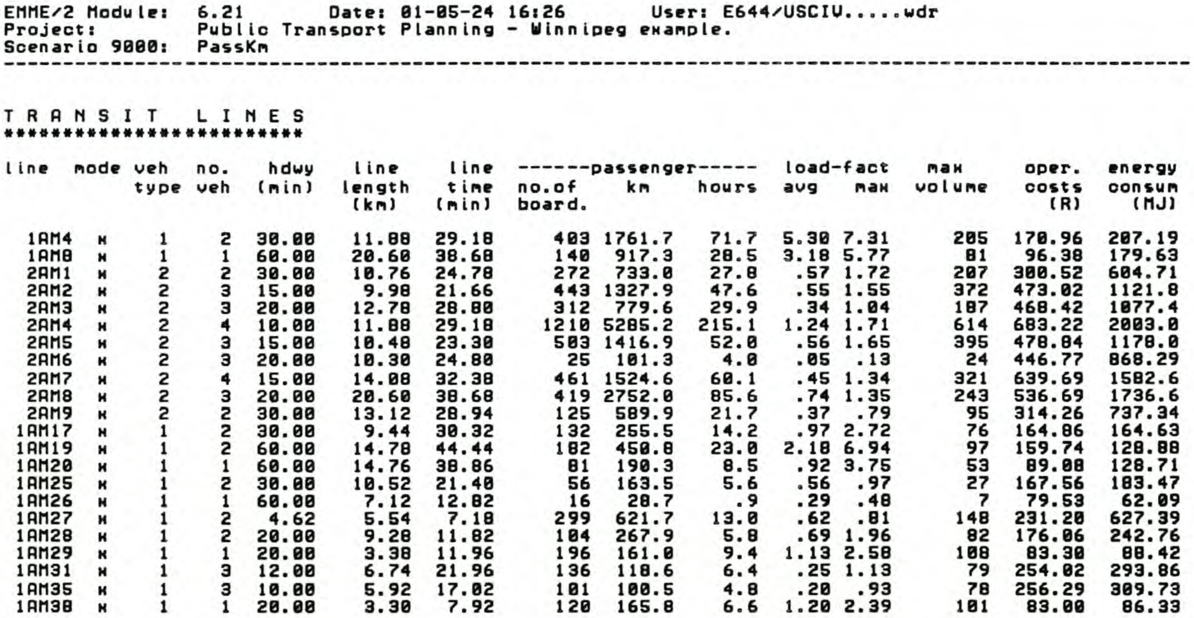
01-05-24 16:12
MODULE: 2.23
USCIV......wdr

Figure 9-17: The Emme/2 graphic representation of the transit lines derived from the route extraction and the resource allocation processes.

The transit assignment process is carried out using Emme/2 modules 5.11 and 5.31. For comparison purposes, the same parameters have been used in the case study as were applied in the Emme/2 example; i.e.:

Demand matrix = mfo2
Boarding time = 2.5
Wait time factor = 0.5
Weights: Wait = 2
Aux = 2
Board = 2

The full results of this assignment are shown in the Emme/2 data bank on the accompanying CD. An extract is shown in Figure 9-18.



```
EMME/2 Module:   6.21        Date: 01-05-24 16:26        User: E644/USCIU.....wdr
Project:         Public Transport Planning - Winnipeg example.
Scenario 9000:   PassKm
-----------------------------------------------------------------------------------------


T R A N S I T   L I N E S
**************************

line   mode veh  no.   hdwy   line    line   ------passenger-----  load-fact   max      oper.   energy
            type veh  (min)  length   time   no.of   km     hours  avg   max  volume    costs   consum
                              (km)   (min)   board.                                      (R)     (MJ)

  1AM4   x    1    2  30.00   11.88   29.18     403 1761.7   71.7  5.30 7.31     205   170.96  207.19
  1AM8   x    1    1  60.00   20.60   38.68     140  917.3   28.5  3.18 5.77      81    96.38  179.63
  2AM1   x    2    2  30.00   10.76   24.78     272  733.0   27.8   .57 1.72     207   300.52  604.71
  2AM2   x    2    3  15.00    9.98   21.66     443 1327.9   47.6   .55 1.55     372   473.02  1121.8
  2AM3   x    2    3  20.00   12.78   28.80     312  779.6   29.9   .34 1.04     187   468.42  1077.4
  2AM4   x    2    4  10.00   11.88   29.18    1210 5285.2  215.1  1.24 1.71     614   683.22  2003.0
  2AM5   x    2    3  15.00   10.48   23.30     503 1416.9   52.0   .56 1.65     395   478.84  1170.0
  2AM6   x    2    3  20.00   10.30   24.80      25  101.3    4.0   .05  .13      24   446.77  868.29
  2AM7   x    2    4  15.00   14.08   32.38     461 1524.6   60.1   .45 1.34     321   639.69  1582.6
  2AM8   x    2    3  20.00   20.60   38.68     419 2752.0   85.6   .74 1.35     243   536.69  1736.6
  2AM9   x    2    2  30.00   13.12   28.94     125  589.9   21.7   .37  .79      95   314.26  737.34
 1AM17   x    1    2  30.00    9.44   30.32     132  255.5   14.2   .97 2.72      76   164.86  164.63
 1AM19   x    1    2  60.00   14.78   44.44     182  450.8   23.0  2.18 6.94      97   159.74  128.88
 1AM20   x    1    1  60.00   14.76   38.86      81  190.3    8.5   .92 3.75      53    89.08  128.71
 1AM25   x    1    2  30.00   10.52   21.40      56  163.5    5.6   .56  .97      27   167.56  183.47
 1AM26   x    1    1  60.00    7.12   12.82      16   28.7     .9   .29  .48       7    79.53   62.09
 1AM27   x    1    2   4.62    5.54    7.18     299  621.7   13.0   .62  .81     148   231.20  627.39
 1AM28   x    1    2  20.00    9.28   11.82     104  267.9    5.8   .69 1.96      82   176.06  242.76
 1AM29   x    1    1  20.00    3.38   11.96     196  161.0    9.4  1.13 2.58     108    83.30   88.42
 1AM31   x    1    3  12.00    6.74   21.96     136  118.6    6.4   .25 1.13      79   254.02  293.86
 1AM35   x    1    3  10.00    5.92   17.02     101  100.5    4.8   .20  .93      78   256.29  309.73
 1AM38   x    1    1  20.00    3.30    7.92     120  165.8    6.6  1.20 2.39     101    83.00   86.33
```

Figure 9-18:An extract from the transit assignment results as given in Emme/2 module 6.21.

This process is not without problems. Emme/2 treats different vehicle operating on the same route as different lines. It thus appears that the service frequency is longer for each vehicle type than is specified in the route definition. An example of this can be seen in lines 1AM4 and 2AM4 in Figure 9-18. These are shown as having headways of 30 and 10 minutes respectively. In fact, the route design is such that the actual headway is 7.5 minutes and the specific vehicles will be scheduled to match short-term demand levels associated with work starting or ending times. Overcoming this problem requires further investigation to ensure that the transit assignment accurately reflects the underlying design intentions.

Another discrepancy exists in the number of vehicles required. This is a result of a failure on the part of the author to make proper provision for the node dwell times at the stops. These are included in the Emme/ assignment process, sometimes resulting in the specification of extra vehicles arising from a longer cycle time.

It will also be noted that a number of lines have average and/or peak utilisation factors greater than 1. Elsewhere, very poor utilisation is encountered. The author has not resolved this anomaly yet but believes it to be due to the Emme/2 "Strategy" approach to transit assignment in which passengers transfer to the line perceived to offer the best travel time. The author believes, and has heard it said by a number of people with experience in public transport, that for short trips in particular, people do not employ the strategy process proposed by Emme/2 but rather stay with a chosen line from beginning to end. This may be a result of a lack of multi-modal ticketing but is as likely to be due to a degree of inertia and risk averseness in passengers.

These issues must be dealt with in detail when carrying out the process in a real application but are not considered critical to demonstration of the overall concept at this stage. The summary results from the Emme/2 Winnipeg example and the route extraction process are shown in Table 9-2.

	Vehicles	Boardings	Passenger Km	Passenger hrs	Average load-factor
Emme/2	509	26421	77432	6908	0.28
Case Study	283	38649	81654	3952	0.36

Table 9-2:Summary of transit assignment results for Emme/2 demonstration model and route extraction process.

There are clearly advantages to both results. The route extraction process line definitions now require adjustment, which is not undertaken here. These adjustments should improve the performance of the route extraction results although it may be expected that additional vehicles will be required. The transit volumes derived from the assignment are shown graphically in Figure 9-19.

Assuming that the lines have been modified to the satisfaction of the planners, keeping in mind that this planning methodology is intended as a design aid, not a push button route generator, the planner can export the boarding and alighting details back to the DSS where this information is used to guide the development of infrastructure. This is done via Emme/2 module 6.21 option 4, "list transit volumes at nodes." This generates a report file that can then be imported into the DSS.

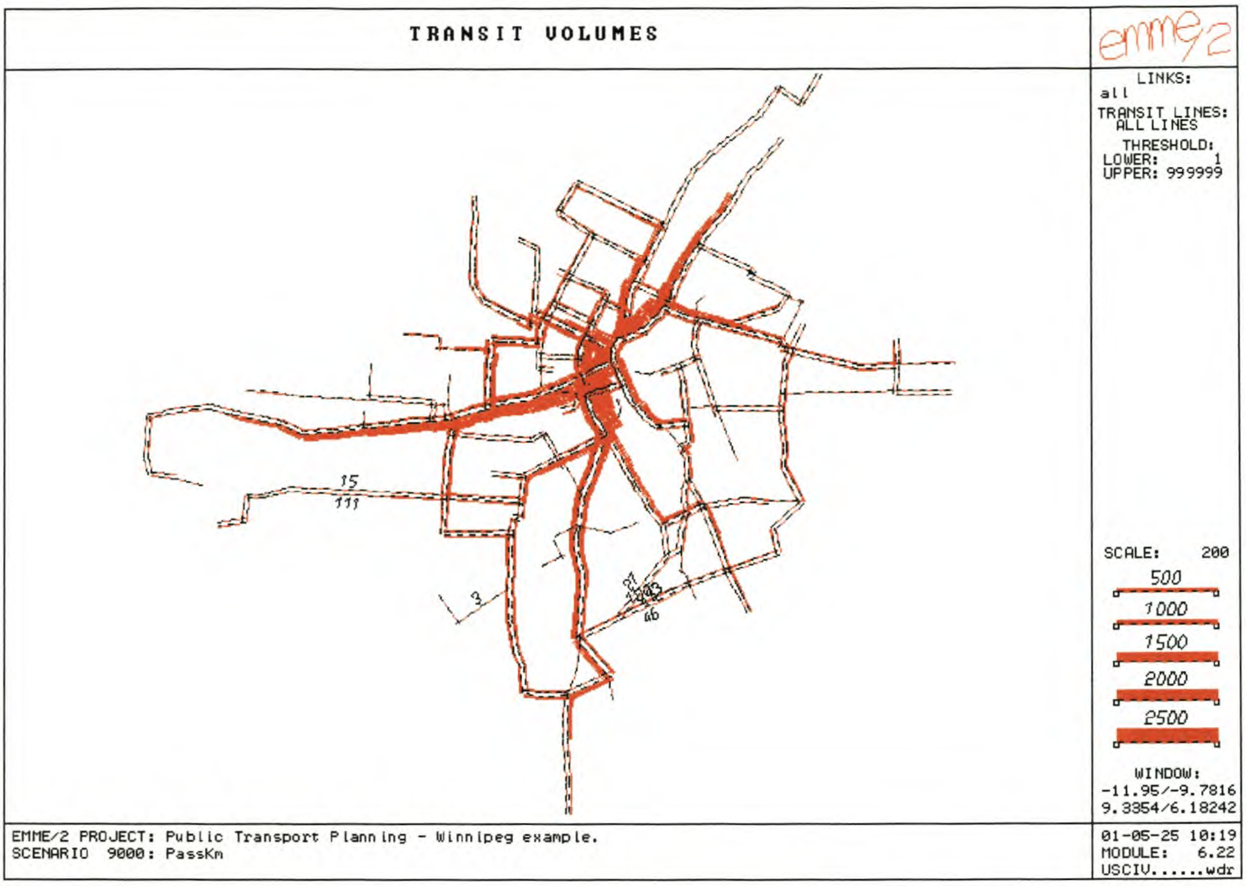
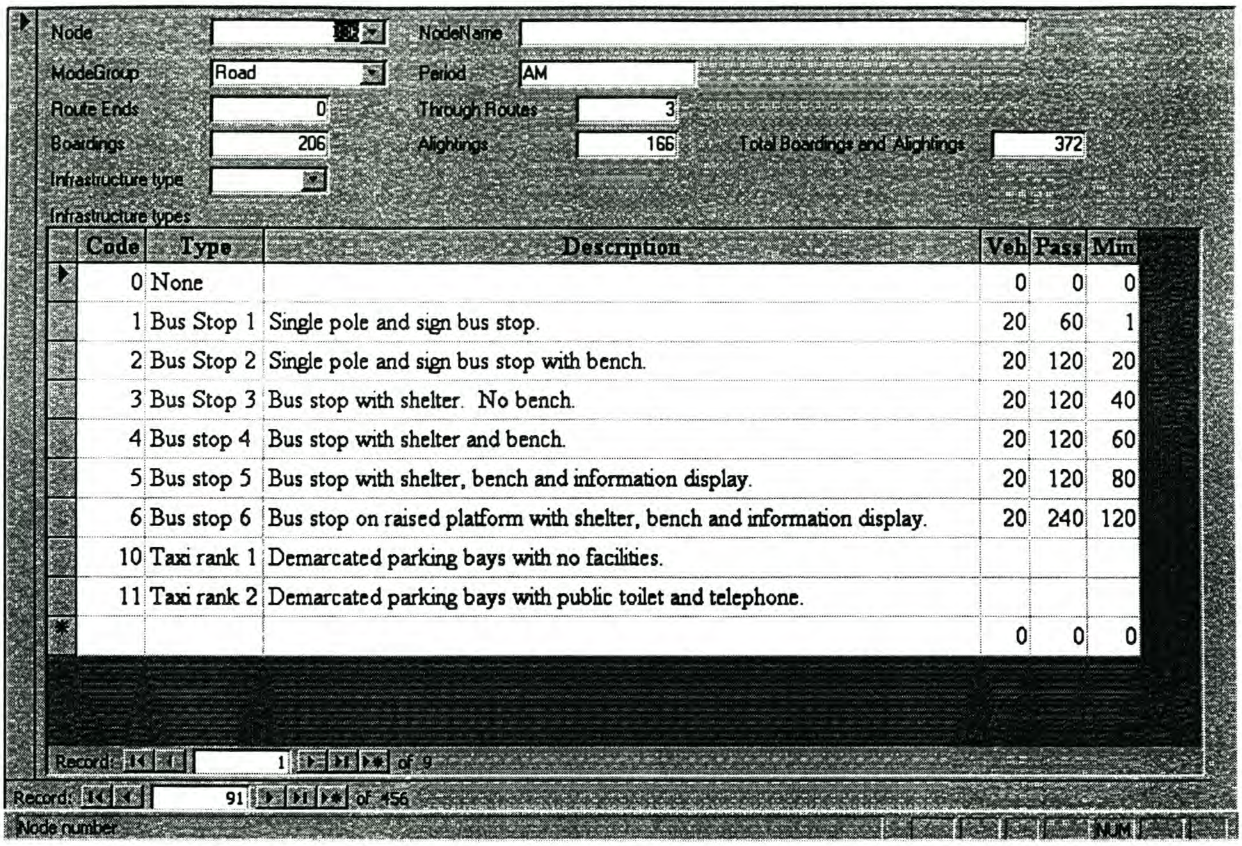


Figure 9-19: The graphic display of the transit assignment results for the route extraction process route specifications.

9.10 INFRASTRUCTURE SPECIFICATIONS

One of the options in the Import / Export module of the DSS allows the import of the "Boardings and Alightings" as determined in the Emme/2 assignment. This information is stored in the table "PassNumbers" in the DSS and this is then further summarised in the "NodeUse" table.

The planner can now access the node data as depicted in Figure 9-20. The data presented here is intended only for example. There are also aspects requiring modification in the detail. In particular, the form needs to be modified to reflect the number of each type of vehicle using the node. Again, this is not believed pertinent to the concepts of the dissertation, being a detail of coding and not of concept. The important aspect is that the planner is presented with detailed information for each node in the system, which allows the best selection of infrastructure or the ascertaining that the current infrastructure is adequate. This information could also be used as a marketing tool when arranging commercialisation of the access node.



Node: [illegible]
NodeName:
ModeGroup: Road
Period: AM
Route Ends: 0
Through Routes: 3
Boardings: 206
Alightings: 166
Total Boardings and Alightings: 372
Infrastructure type:

Infrastructure types

Code	Type	Description	Veh	Pass	Min
0	None		0	0	0
1	Bus Stop 1	Single pole and sign bus stop.	20	60	1
2	Bus Stop 2	Single pole and sign bus stop with bench.	20	120	20
3	Bus Stop 3	Bus stop with shelter. No bench.	20	120	40
4	Bus stop 4	Bus stop with shelter and bench.	20	120	60
5	Bus stop 5	Bus stop with shelter, bench and information display.	20	120	80
6	Bus stop 6	Bus stop on raised platform with shelter, bench and information display.	20	240	120
10	Taxi rank 1	Demarcated parking bays with no facilities.			
11	Taxi rank 2	Demarcated parking bays with public toilet and telephone.			
			0	0	0

Figure 9-20: Node use data with infrastructure type selection and specification.

9.11 REFERENCES

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10 CONCLUSIONS

This dissertation has described concepts that can be used to develop and maintain a public transport system for an urban area. This process includes network modelling in which the interaction of all modes and categories of transport are considered and in which a compromise is reached between the desires of the customer and the ability of the providers of public transport. The process further allows for the inclusion of urban planning policy in the network model. The network modelling phase on its own can be used to provide the logical basis for the development or improvement of the public transport system and the associated infrastructure.

The process then moves on to the conversion of the network model results into potential public transport routes or lines. As with the network-modelling phase, the process seeks to find a compromise, this time between transfers and service frequency. This is achieved through seeking out routes along paths of maximum demand that are able to sustain a given level of service with a given class of vehicle. A by-product of this process is information that will guide the siting of fixed infrastructure. Again, the results of this process are adequate to provide the planner with a good basis for the more detailed design of routes and the assignment of vehicles and operators to the different routes.

The next step is to seek the optimum assignment of vehicles to the routes, mainly in the road based segment of the system. This involves a two pronged approach; One, the accurate assessment of individual vehicle operating costs and; Two, the specific assignment of vehicles to routes according to a variety of possibly conflicting objectives. The vehicle costing process also allows the planner to determine the optimum working hours and travel distance for each class of vehicle so that the overall design may seek to achieve these conditions by selecting the appropriate number of each type of vehicle for the system. The vehicle costing has the additional benefit of making it possible for the transport authority to offer advice and assistance to the small operators who may not be in a position to carry out such analysis themselves but who wish to play an active role in the system.

The entire process is based on the concepts of strategic logistics management in which all aspects of the public transport system are considered in the design process albeit that there are many opportunities to improve on the detail of the proposed concepts.

The motivation for proposing this approach to public transport system design is that in South Africa, changing conditions have made such planning essential to the survival of the public transport system. This system has been developed based on "artificial" urban structures that are now disintegrating and current government requirements are for comprehensive, integrated transport plans with a strong emphasis on public transport. This requirement is accompanied by a lack of resources and thus requires effective but inexpensive planning methods.

An important aspect of the required transport plans is that provision must be made for the previously disadvantaged to participate, meaningfully and in a structured manner, in the provision of public transport. This in turn means being able to incorporate a range of diverse vehicle types into the system.

Even in those parts of the world where such change is not taking place, there are nevertheless constant changes in the overall urban structure. The author believes that a revision of the public transport system taking into account these changes in a region-wide way could lead to significant improvements. It is thus his contention that the process has merit as a review mechanism to be employed on a regular basis in any city in which public transport plays a role.

The decision support system and overall process, as presented here, are not without problems but these are of a technical nature and can be resolved using improved programming. It is the author's belief that the concepts presented can be used by any transport planner to develop the basis for a public transport system design without the need of very expensive software or expertise. In so doing, the author believes that the proposed system fills a gap in the literature, that of providing a basic set of tools for the design of a functional public transport system. The planner can then move on to use the more conventional software which examines the efficiency of proposed routes but which, in general, does not propose any routing itself.

11 RECOMMENDATIONS

There are four main recommendations arising from the research and development presented in this dissertation. These relate to:

- The software used.
- The detailed coding
- The implementation of the concepts in practice.
- The integration of the focusing concept into commercial network modelling packages.

11.1 THE SOFTWARE

A number of relatively straightforward techniques for the design of a public transport system have been demonstrated using either commonly used or relatively inexpensive software. None of the software used was vital, in itself, to the process. In fact, two software specific problems were encountered in the design. The first of these is that MS Access has a problem that results in the database expanding uncontrollably during the route extraction process. This is a known problem with the package. The second is that it was found that the Lingo operations research package was actually somewhat less than ideal when compared with some other packages, such as the GAMS-CPLEX combination.

Thus, it is recommended that the first step in taking the process forward towards practical implementation, is to eliminate these two problems. The MS Access problem can be resolved by making use of MS Visual Basic independently of MS Access or by using a different database language although the latter approach will possibly require the complete re-writing of the DSS code. (Visual Basic uses the same database engine as MS Access and so it is possible to externalise the code currently contained in the database without losing the basic database structure.) The use of Visual Basic as a separate package to drive the process allows the repeated compaction of the database during the extraction process, thus eliminating the effect of the expansion problem.

The operations research software is a slightly different problem. It is known that the LINGO models presented in this dissertation can be run using the GAMS-CPLEX software and the GAMS-EXPRSS software. There may be other solvers, not able to use the LINGO model, that are capable of solving the allocation model even more efficiently. (OPL and AMPL, with which the author is unfamiliar, have been recommended.) Research is required into the selection of a more suitable modelling and solver combination and the possible revision of the allocation and other Operations Research models to better suit the ultimately chosen package.

11.2 THE CODING

As mentioned, the computer code presented in the dissertation and DSS are for demonstration purposes – the author does not purport to be a highly proficient computer programmer – and thus all the code needs at least some revision to bring it to commercial standards. This applies to all facets of the process, ranging from the network model macros through the route extraction process to the resource allocation model although the author is confident that conceptually at least, the code presented is functional and correct. The re-coding must be considered from three perspectives:

- Modification of the current code.
- The use of different techniques.
- The use of different software.

11.2.1 Modification of the current code.

Assuming that the basic current code is to be utilised, there is scope and in fact, a need, to improve the quality and detail of the code, particularly that of the route extraction process. One of the most important facets of this will be the proper coding necessary to deal with the one-way street issue. This particular modification extends into the DSS database structure as well.

In particular, the author believes that a worthwhile exercise will be to transfer most of the Visual Basic code from the DSS database to a standalone Visual Basic application so as to eliminate current problems with the database arising out of a limitation in MS Access. This will mean some minor modification of the code rather than a major re-write at the most basic level but could involve a somewhat more extensive amount of work if implemented to the fullest degree in which the MS Access database became redundant. This latter is the route recommended for formal commercialisation of the package although it will result in some loss of user flexibility.

11.2.2 The use of different techniques.

The author believes that there are a number of ways that each step of the process could be implemented, some different only in the detail and some at a more fundamental level. In respect of the latter, it was mentioned that the route extraction process can be performed, with some benefits and also some possible problems, using a modification of Dijkstra's algorithm as presented in APPENDIX K. The author believes that this is an area of investigation worth further research as it offers the benefit of eliminating the arbitrary aspects of the current process arising out of the sort order of the links in the database. It also provides a more mathematically appealing solution to the extraction process although not necessarily a better one.

Equally, there may be alternative ways of structuring the allocation model which make it easier to solve and more flexible in the hands of the user.

11.2.3 The use of different software.

In the event that different software is chosen for the implementation of the public transport system design process, re-coding will be required to accommodate the different software. This applies at all stages of the process. The Emme/2 macros will not work with other network modelling packages. The Visual Basic code which translates between Emme/2 and the database will need to take into account a different network model or database package and structure. The MS Excel and LINGO models are based on particular database structures and code.

There are clearly weaknesses associated with some of the packages employed in the demonstration version and there may thus be justification in changing to different software entirely. For example, C++ is likely to offer significantly better performance over Visual Basic and, as mentioned, GAMS-CPLEX an improvement over LINGO. Research is thus required into the best software for implementing each phase of the modelling process, keeping in mind the need to keep costs to a minimum. The latter implies that the rest of the system should be independent of the Network model, which will usually be an established component of the urban area's transport planning system.

11.3 IMPLEMENTATION OF THE CONCEPTS IN PRACTICE.

In order to evaluate the worth and usefulness of the design process, described in this dissertation, it is necessary to implement the concepts in a real study where the results can be evaluated against the realities. It is the author's intention to seek the opportunity to do this but it would also be of value to have the process evaluated in detail by a less biased party. Opportunities to do this are not that common, South Africa however, offers several such opportunities at present because of the integrated transport planning required by central government.

11.4 THE INTEGRATION OF THE FOCUSING CONCEPT INTO COMMERCIAL NETWORK MODELLING PACKAGES.

Transport problems are going to be with us for some time to come and for as long as they are, there will be some push towards maintaining an attractive public transport system. The focusing process as presented in this dissertation, allows the planner to develop, at very least, an outline of the public transport system layout. It simultaneously allows an examination of the interaction of the public and private transport modes.

It is the author's belief that the focusing process proposed for use in the network modelling process has distinct merit on its own. It also seems reasonable to believe that the process could be far better implemented within the commercial network modelling packages as part of their inherent structure. It is thus the final recommendation, that such inclusion should be given consideration by the developers of such commercial software.

11.5 CONCEPTUAL IMPROVEMENTS

In addition to the preceding recommendations, at least one conceptual improvement suggests itself to the author upon contemplation of the work thus far. In the network-modelling phase, one multi-class assignment was used followed by a number of single-class assignments. The result of this approach is that there will be a divergence from the original link travel times as the process proceeds. A better approach will be to note that the express routes are essentially only road mode routes and to create an additional auxiliary-auto class for this demand category. Class-specific volumes are then saved for each class and the focusing process is performed using a series of multi-class assignments with the regular public transport demand forming the primary class throughout.

This approach will maintain more realistic travel time estimates and may further allow for more co-ordination between regular and express routes by constantly including both in the assignment process. There may also be a basis in this approach to allow for implementing of variable demand and mixed private-public transport trip modelling.

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The following list includes literature that has been consulted by the author, not all of which is specifically referred to in the body of the text but which may nevertheless be of interest to the reader.

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APPENDIX A.

THE DECISION SUPPORT SYSTEM

This Appendix is intended as a guide to the computerised decision support system (DSS) which implements the concepts presented in the body of this dissertation.

A.1 INTRODUCTION

In a small business, the evaluation of the business operating data can be carried out manually. In a large business however, there are often too many factors to be taken into account without some sort of computerised assistance. This is the function of a decision support system, (DSS.) In such a system, large amounts of data are assimilated over a period. This data is then subjected to tests associated with the business parameters and the analysis results are then used by management to direct the activities of the business.

The preceding chapters have described various aspects of the public transport planning and management process in terms of distinct activities. These activities are however interdependent, based on a set of common goals and rely on common data. This leads to the argument that the various activities should be seen as a whole and should work together as a system. To this end they have been incorporated, as far as is possible, into a decision support system in which models of various system components are linked. Such a decision support system is the tangible product of this research, albeit in demonstration form.

Lambert and Stock (1993) give the following definition of a decision support system (DSS):

> An integrative system of subsystems that have the purpose of providing information to aid a decision-maker in making better choices than would otherwise be possible. The subsystems that are commonly associated with a DSS are the following:
>
> - Decision-relevant models
> - Interactive computer hardware and software
> - A database
> - A data management system
> - Graphical and other sophisticated displays
> - A modelling language that is "user friendly."

This dissertation has focused primarily on the first of the listed subsystems, the decision relevant models that have been described in previous chapters. Each of the other elements is however, incorporated in the overall DSS to some extent or another. This chapter seeks to provide a brief overview of the decision support system structure so that the reader can obtain a picture of how the decision relevant models are coupled.

This overview is intended to demonstrate the form of the DSS. As will been seen, the entire decision support system is in an open format. That is to say, there is no restriction on the addition of components to the database or DSS. This extends to allowing the inclusion of additional Lingo and Excel models or the use of more than one network-modelling package. The result is that the DSS can be adapted to the particular needs of the planner or project rather than requiring adaptation of these to the DSS. All the components described here are provided on the accompanying CD. The contents of the CD are presented in section A.7.

A.2 THE DECISION SUPPORT SYSTEM COMPONENTS

As noted in the introduction, this dissertation describes the principles used in the development of a computerised decision support system (DSS) for the implementation of strategic logistics management principles in the planning and operation of urban public transport. The dissertation is not a user manual for the DSS but cannot be complete without some discussion of the elements of the DSS. This system comprises the following main components:

- An Emme/2 network model
- A Microsoft Access Database
  - A Visual Basic route extraction program
  - An Excel spreadsheet vehicle cost model
- A Lingo resource allocation model
- A Lingo tender evaluation model

A.3 THE EMME/2 MODEL

The Emme/2 network model is well known and has been discussed at length in Chapter 4 and thus requires little further discussion. It is important to note however, that within the context of the DSS, Emme/2 forms part of the system database. A great deal of information is required in order to carry out the network modelling process and is stored in the Emme/2 databank. There is data, having no purpose outside of the network model, which does not appear in the Access database, as this would be an unnecessary duplication. There are exceptions to this however, particularly with respect to link and node data, which are used in the route extraction and the infrastructure planning processes.

The Emme/2 program supports automated processes through the mechanism of macros. Since the DSS uses several repetitive processes, it is possible to automate many of the processes described in Chapter 4. Many of the macros used in the development process were very simple and do thus not warrant comment or inclusion in this dissertation, a few do however justify inclusion:

ModeChng — This macro prompts the user for the identifiers of the current auto mode, the new auto mode, and the new global mode. It then creates a new auto mode as an auxiliary auto mode, deletes the old auto mode, and creates the new global mode. The mode and link tables are updated in the process to reflect the changes. The result is that the original auto mode is able to access exactly the same parts of the network as before, as are all other auxiliary auto modes. There is now also a "global" mode, which is used by the public transport users and which can use all links in the network.

Comp — This macro automates the focusing process for a single period allowing that the user must create a copy of the current scenario, and change to the new scenario before running the macro. The macro copies the demand penalty and index from the last scenario to the latest scenario. It then uses these to perform a new assignment and finally, it calculates the new link index and demand penalty for the next scenario.

SendData — This macro prompts the user for the path and name of the files to which the Emme/2 results must be output. It then punches the results of the scenarios representing the express and the conventional public transport services. These punched files are the input to the database and subsequent processing.

It should be noted that these macros are written for the example study rather than as generic macros and would thus need modification for other models or for more commercial application. Another point of note is that the DSS is not restricted to Emme/2. Whilst it may mean some minor changes, particularly to the interface between the network model and the DSS database, any suitable network modelling package can be used. Some of the more recently developed packages of this sort are based on GIS concepts. The GIS approach requires a more flexible database structure than that provided by Emme/2 at present and there may thus be a data overlap with the DSS database when using one of these packages instead of Emme/2.

A.3.1 Network model – Database interface

The SendData macro creates a number of text files in Emme/2 output format. These files contain the data necessary for the route extraction process as well as for the specification of other aspects of the system design, such as the siting of infrastructure. The import and export processes are coded within the database but the identification of the input and output file names and paths is handled by a separate program. This program, SystemData.exe, is written in Visual Basic 5.0. When called, this module provides a file handling routine so that the user can select the various files to be used in communications between Emme/2 and the Access Database. The file names and paths are stored in the database as is the path of the module itself.

A.3.2 The database

At the heart of the DSS is a Microsoft Access database. This database stores the data and much of the code required for the public transport system design process. The database is split into two sections:

- A project dependent data section.
- A project independent user interface.

Although MS Access is able to handle almost unlimited quantities of data when suitably structured, it is not particularly efficient in such circumstances. For a large metropolitan area where it is intended to develop a true electronic data interchange decision support system, one of the larger database packages, such as Sybase, Oracle or Delphi may prove to be more suitable. Irrespective of the software, the concepts will remain the same.

The list based nature of the database specification and the table contents are not conducive to their inclusion in this chapter. The complete database, with sample data for the case study and other examples in the dissertation, is included on the compact disc that complements this document and the structure of the database can be examined in detail there. The important elements will however be discussed in later sections of this chapter.

A.3.2.1 The project dependent data section

This is a standalone database which can reside anywhere on the computer and which may be duplicated and named for each project. Only the project data is stored in this database. This data includes:

- The network configuration data.
- Emme/2 specifications, modes, graphics parameters etc. – used to construct Emme/2 input files.
- The traffic assignment results.
- The fleet data which includes vehicle and operator data.
- Infrastructure information.
- Policy information and goal program weights.
- Various tables used specifically by the route extraction and resource allocation processes.

A.3.2.2 The project independent user interface

This is also a standalone, database and has no connection with any particular project. It is used as an interface between the DSS and the current project database. The database contains:

- The menu system
- All the code required for the route extraction process and other data manipulation.
- Interface forms, queries, reports and macros to process, view, edit, and print the data in the project database.
- The auxiliary models stored as OLE (Object Linking and Embedding) files for portability. These include:
  - Lingo models
  - Excel spreadsheets
  - Emme/2 macros
- System information. This includes the paths of the external files used, such as the spreadsheets. (This is set up manually on the first installation of the database.)

The user selects the project database to be used from within the interface database. The DSS is structured so that once the project database is selected, the user perceives only one database.

A.3.3 The Resource allocation model

As with the network model, a separate chapter has been devoted to the details of the resource allocation model. It is however a standalone component of the DSS and has some features not pertinent to the mathematical model which require attention.

Theoretically, this model can be run from within the database without being visible to the user. This requires a particular form of the model to be created and saved within the database and leads to problems in modifying the model and analysing the results for each project. The DSS is thus designed so that the interface database carries the model as an OLE object, which is then saved as a separate file and run under Lingo directly. The allocation model is thus a separate component of the DSS that can be modified and run independently of the database.

In order for Lingo to communicate with the database, the database must be specified as an ODBC (Open Database Connectivity) data source. This is done through the operating system. In Windows, the ODBC set-up program is accessed through the Control Panel. The important issue is that the ODBC data source name must be the same as that specified in the Lingo model by the "Title" statement. In this model, the name "BatchData" has been used but this may be changed by the user as long as it is changed in the Lingo model and ODBC specification. With the ODBC data source specified, Lingo is able to read from and write to the database. Used in this way, a licensed copy of Lingo 6.0 (or higher) is required. It is possible to obtain a runtime license that will run the allocation model without giving any access to Lingo itself. This may be useful option in a commercial application of the DSS.

A.4 THE PROJECT DATABASE

The project database is one or more standalone database files that contain the data describing the public transport system. In the examples provided here, only one database file is used for each project but this can easily be changed, especially where Electronic Data Interchange (EDI) is to be used and access to data is to be restricted. The structure of the data storage can only be altered from within this database. The data has a number of forms:

Network model definitions. These are used when files are created in the Access database for input into the network model. Examples are the line colours and patterns for entering the transit line definitions into Emme/2. This data is project independent in general but is kept within the project database, as there is no reason that every project should be associated with the same network modelling package.

Base data. This data is fundamental to the system and includes node and link data, input costs, quantities, goal values and so on. Although the data may be changed, it is not modified by any process in the DSS. This means that the DSS processes can be repeatedly run with the same base data to test specific changes to one or other parameter.

Process control data. There are many steps in the overall modelling process where the planner can influence the direction of the solution. This is done through process control data which is modified by the planner, each modification resulting in a slightly different possible system design. This data can be thought of as the user interface or "what if" data.

Process data. During the actual processing of the data, particularly during the route extraction process and less so during vehicle cost analysis, temporary data is stored. This temporary data is converted, at the end of processing, into a more suitable form for the user. At the end of processing however, much of this intermediate format data is kept and may be useful in analysis.

Result data. At the end of the processing task, a number of tables are generated containing the process results. Examples are descriptions of the routes including vehicle allocation, and estimated revenue and cost.

A.5 THE INTERFACE DATABASE

The interface database, unlike the project database, contains almost no data at all. As the section heading implies, the function of this database is to provide the interface between the user and the data. It also acts as the container for the process models incorporated in the DSS. This interface is mainly carried out by means of "Forms" which will be described shortly, there are however a number of other elements in the database.

A.5.1 Tables

Tables are the repositories of raw data in a database. The little data that is kept with the interface database relates to the models that make up the decision support system, for example, the resource allocation model and the vehicle cost model. All other data is accessed via a process known as "linking." The data in the project database is linked to the interface database and to the user, appears to be stored in the latter. The data can be edited but the data structure cannot be modified from within the interface database.

A.5.2 Queries

The data described above is not always kept in the same table as the other data with which it may be expected to be kept. Sometimes, data entry and processing are better achieved with a different grouping of data. Because of this and the need to be selective in the processing of the data, queries are used. These are essentially small programs which group and filter the data from one or more tables to show it in a format most suited to the immediate need. Most of the processing of the data is done through these queries.

A.5.3 Forms

Just as the tables do not always contain the data in the correct groupings, neither the tables nor the queries are usually suitable for presenting the data, which is shown in a tabular format like a spreadsheet. Forms are used to show the data in a particular way, again with opportunity for grouping and filtering.

A.5.4 Reports

Although data can be printed out directly from tables, queries and forms, the result is usually awkward to read. Reports are structured printout instructions for particular data sets. These are relatively easy to set up and can be created to suit the planners needs.

A.5.5 Macros

Macros are "mini" programmes. These are used only in a limited way in the DSS, full code programmes usually being somewhat more versatile.

A.5.6 Modules

In MS Access, modules are computer programs using a version of the programming language Visual Basic. Most of the DSS functionality derives from the code provided in these modules. In the form in which the DSS is presented on the accompanying CD, these modules can be opened and viewed or edited.

A.6 THE MENU

Whilst it is expected that anyone using the DSS as presented here will be familiar with the use of MS Access, the user cannot be expected to have a detailed knowledge of the DSS. Thus, the DSS should guide the user through the design process. This is achieved by the use of a menu system. This menu system is layered so that each group of processes is clustered together. Some processes are relevant to more than one section and so appear in more than one menu. These menus are discussed briefly to lead the reader through the DSS process. Many of the menu items, such as "Return to Main Menu" are self-explanatory and are not discussed.

A.6.1 Main Menu

This menu opens automatically when the DSS database is opened. Each of the menu commands bar the last two call a sub-menu.

- Import - Export Functions
- Network model interface Menu
- Vehicles Menu
- Routes Menu
- Resource Allocation Menu
- System Menu
- Return to DataBase

  Closes the menu system and returns the user to the standard MS Access database window.
- Exit DataBase

  Close the current database. MS Access is not closed.

A.6.2 Import-Export

- Import / Export

  Opens a form allowing the user to select the data to be imported from or exported to Emme/2. The transfer is carried out via Emme/2 batch files, not by direct manipulation of the Emme/2 databank. Although direct databank manipulation could be used, the benefits do not justify the risk of corrupting the databank.
- Edit Import / Export Filenames and Paths

  Calls an external file-handling program to define file names and paths used by the system.
- Return to Main Menu

A.6.3 Network Data

- Add / Edit Modes

  Displays the network model mode data and allows this to be modified.
- Add / Edit Mode Groups

  Displays the Mode Group data and allows modification. This information is used in the DSS to separate road from rail etc.
- Add / Edit node data

  Displays the network model node data and allows modifications, such as the adding of node names and interchange data. (Bus stop type for example.)

- Add / Edit link data

  Displays the network model link data and allows modifications, such as the adding of street names and vehicle restrictions.
- Edit / View One-Way link data
- View / Edit program presets

  Opens the Network Program Presets Menu.
- Return to Main Menu

A.6.4 Network Program Presets

- Add / Edit line colour codes

  Displays the line colour codes used by the network model in its graphic displays. These can be edited.
- Add / Edit line pattern codes

  Displays the line pattern codes used by the network model in its graphic displays. These can be edited.
- View Mode definitions

  Displays, but does not allow editing of the mode definitions used by the network model. In Emme/2 these are Auto, Transit, Auxiliary Auto and Auxiliary Transit, each with a code number.
- Return to Network Menu
- Return to main menu

A.6.5 Vehicle Data Menu

- Add / Edit Vehicle Data

  Displays a form allowing addition or editing of vehicle information.
- Edit Vehicle Cost Spreadsheet

  Gives access to the embedded MS Excel vehicle cost spreadsheet.
- Add / Edit Operator Details and Vehicles

  Displays a form allowing addition or editing of operator information.
- Add / Edit Energy data

  Displays a form allowing addition or editing of energy source information. (Fuel costs, units of measurement, energy values etc.
- Return to Main menu

A.6.6 Routes Menu

- Perform Route Extraction

  Displays a form to allow specification of operating period to be evaluated. Controls are provided to allow return to menu or activation of extraction programme.
- View / Print Summary Routes report

  Displays and allows printing of a summary report of the route extraction process results.
- Edit Route Extraction variables

  Opens a form in which the parameters for the route extraction process are set. Provides controls to proceed to operating period specification form.
- View / Edit Route Details

  Displays the route details in full, route by route.
- Add / Edit Operating Periods

  Displays a form allowing addition or editing of the operating period specifications.
- Interchange Menu

  Open the interchange details menu.
- Return to Main Menu

A.6.7 Resource Allocation

- Add/ Edit / implement Resource allocation models

  Gives access to the resource allocation and other associated Lingo models. These can be opened from this form.
- Edit LINGO Parameters

  Displays a form allowing editing of the goals, rankings, and bounds for the resource allocation process.
- Edit Route Data

  Same as View / Edit Route Details in Routes Menu.
- Add/Edit Vehicle Data

  Same as Add / Edit Vehicle Data in Vehicles Menu
- Return to Main Menu

A.6.8 System Settings

- Edit external program paths

  Displays a form allowing editing of the path specification for eternal programs used by the DSS. This is to allow for transfer between computers.
- Design Application

  Allows the user to modify the menu system.
- Clear process data from database. (Keep base data.)

  Clears all calculated data from the project database. The base data is not deleted.
- Clear all data from database.

  Clears all data from the project database, leaving the structure only. Used to make a new Project Database.
- Return to Main Menu

A.6.9 Interchange Menu

- Add / Edit Interchange Details

  Displays a form allowing adding and editing of interchange details for each node based on the number of transit lines using the node, the boardings, alightings and the range of modes accessing the node.
- Add / Edit Interchange types

  Displays a form allowing adding and editing of interchange facility details. (Facilities range from single post bus stop upwards.)
- Return to Route Menu
- Return to Main Menu

A.7 THE COMPACT DISC

As has been noted in previous chapters, this document is accompanied by a compact disc. This has been done to enable the reader to view and examine the DSS structure and the code associated with the route extraction process. This latter is quite extensive and is only of interest to the specialist reader and is most easily followed in its original environment where the debug process can be used to step through the code, line by line.

The CD contains all the models presented in the dissertation, the full result tables summarised or discussed in the dissertation, this document, and the master's thesis that preceded this research. The contents are structured so that each category of data is kept in one directory that is further split into a sub-directory for each project. Other sub-directories are used to store ancillary data where necessary. For example, all files relating to each of the Emme/2 models are kept in the relevant Emme/2 sub-directory. These files include the emme2ban file as well as the batch input and output files associated with the model. The input files use the extension ".in", which can be opened and viewed using a text editor such as Notepad or WordPad. The following directory structure is used:

Emme2
  - Macros
  - Transit
  - Winnipeg

MS Word

MS Access
  - Transit
  - Winnipeg
  - Mini-Example

Visual Basic

Lingo
  - Transit
  - Winnipeg

- **Excel**
  - Mini-Example
  - Vehicle-costing.

It is assumed that the reader has access to licensed copies of Emme/2 and Microsoft Office Professional 97 or later. The latter includes Access, Excel, and Word. (Most modern software is able to open files from other packages and so most of the documents should be accessible even without Office 97 but some of the functionality may be lost.)

Most of the Visual Basic code is contained within the database and can be examined there. There is a stand alone file handling routine created using Visual Basic 6.0. This particular program is only used for file handling and is of little interest in itself. It can be viewed using a text editor if the source software is not available.

The installation file for the demonstration version of the Lingo software is contained in the Lingo directory and will allow the reader to view the models and the results but not to run the Winnipeg case study. The demonstration version includes a full help function and many other examples and is fully functional within the licence specifications.

A.8 REFERENCES

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APPENDIX B.

THE DATA REQUIREMENTS

B.1 INTRODUCTION

A business starts out by setting itself goals, defining what it wants to achieve, how and when — the basis of the strategic business plan. These goals are used as targets to model the course of action to be taken by a company at any time. The business models act on the data describing the conditions in which the business is operating. Such data must be selected, gathered, stored, and suitably processed to be of any value. This chapter seeks to briefly address the issue of "data," not in the context of the conventional transport modelling, but rather in terms of the strategic logistics management concepts underlying this dissertation.

Data in the management process may be categorised into three groups:

- Strategic specifications. The goal or target values set by management.
- System conditions. The current and projected system descriptors for both demand and supply.
- Process specifications. The output data of the management process describing how the business must proceed. These are the product and marketing specifications.

The input and output data and the intervening management processes for a public transport system are shown schematically in Figure B-1.

As can be seen, there is a range of input information required in order to carry out the management process. This process in turn produces information that must be available to the various production departments. The performance of the entire business is continually monitored and this gives rise to updated input information upon which management can base future decisions.

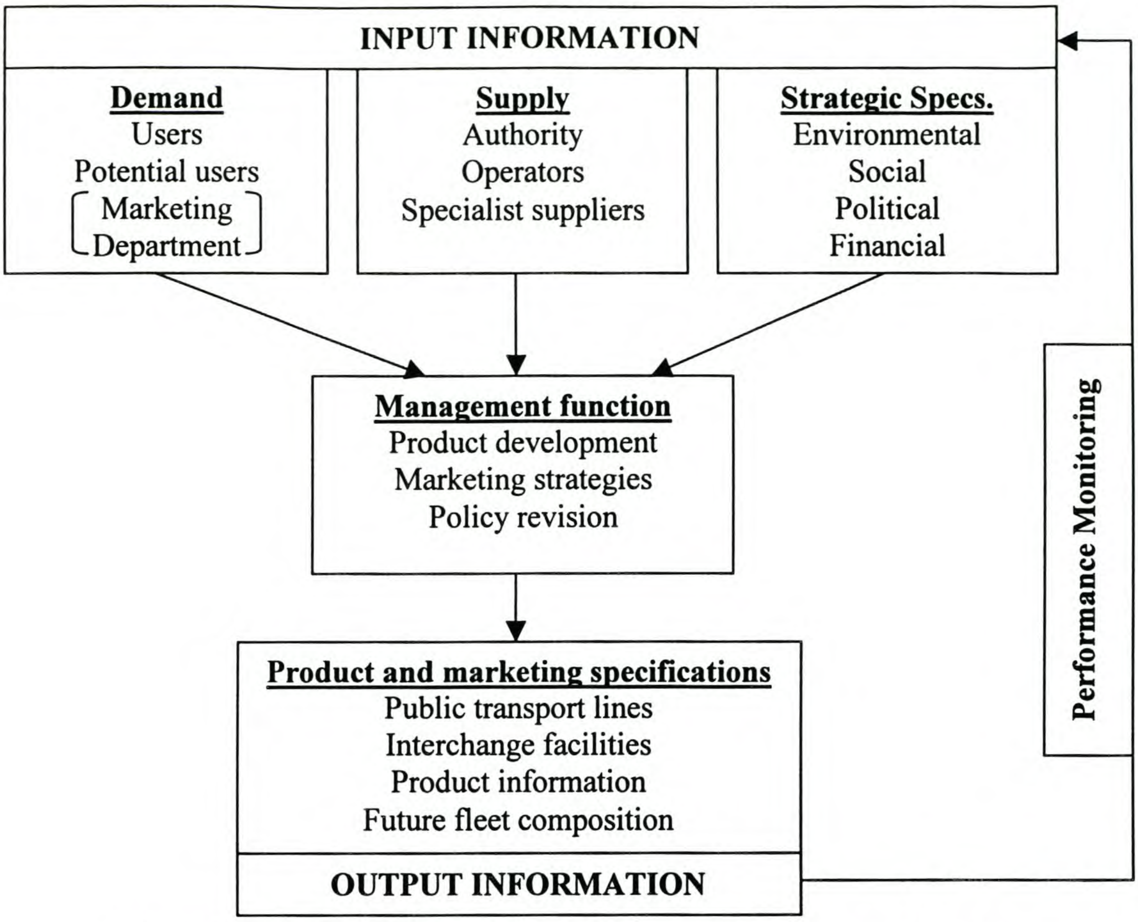

Figure B-1: A simple data model for a public transport authority.

B.2 BASIC DATA CRITERIA

One of the primary uses of data is for planning purposes. Even data, apparently monitoring the current performance is really used for planning. When a correction to the process is made based on this data, a particular action is taken based on the value and trend of the data. This being the case, irrespective of the specific nature of the data, it must satisfy certain basic criteria. It must be:

- Up to date
- Relevant
- Cost effective

These rules apply to both the process input data and the output data, be it for process control or for customer information.

B.2.1 Data currency

In order to be of value, data must be current. The world is dynamic and decisions based on yesterday's conditions are liable to be less than ideal. The customer wants the current timetable, not last season's. In the public transport industry, the product must always be in the right place at the right time – if it is not, it is lost. This means that, although demand patterns are relatively constant in the short term, the planners and operators must be constantly aware of changing conditions. The implication is that data capture must be a continuous process. Fortunately, the nature of public transport is such that much data, such as ticket sales, is captured for a number of reasons, thus spreading the cost of the data. Simple techniques can be used to add to the value and currency of the data. For example, on-vehicle drop-in-a-box surveys can be used to assess travel demand not catered for or information on current route choices or the customer perceptions of service quality.

B.2.2 Data Relevance

Data acquisition, analysis and dissemination are generally expensive. It is thus desirable to keep the data requirements to a minimum. This will also improve both the quality and flow of data. If customers or potential customers are constantly confronted with long and complicated questionnaires, they will quickly lose interest. If they are only asked for a few answers, they are likely to be more forthcoming. The same rules apply to advertising and product information for customers – too much detail will only hide the relevant facts. Of course, data is also required from sources other than the customers, but the same rules apply. In other words, only data relevant to planning and process monitoring should be gathered directly. Identifying the requirements may take some effort, given that a great deal of non-technical data may be of use to the marketing department, but this will save time and money in the end. Always, the question must be asked – will knowing this have any value to the business? The answer may change in the future, but too much data can be as useless as too little.

B.2.3 Cost effectiveness

Data is only of value when the benefit to be derived from having it exceeds the cost of acquiring it. This is usually a matter of collection frequency. Some things only need to be known in immediate terms – for example, the cost of paint to re-spray a vehicle. What the price was, last week, is irrelevant and predicting the price or the future of little great value. Continuously monitoring the cost of paint is thus wasteful. Other data is required on a more or less continuous basis – such as travel demand. Continuous data allows the development of the trend models necessary for product development and production planning. There are occasions when this requirement must be examined with long, rather than short-term goals in mind, especially advertising, where it may take several years to create a new mindset favouring public transport.

B.3 SOURCES OF DATA

From the planning and management perspective, the transport business usually relies on the co-operation of a number of "independent" participants, beside the customers, who both provide and use data on the system. (The independence is relative – the system usually requires most of the role players in order to function.) Although Figure B-1 shows a logical structure for the information in terms of the management process, the information is usually obtained from different sources as shown in Table B-1.

	Authority	**Operators**	**Specialist suppliers**
Demand	SP/RP demand data	Ridership	
Supply	Network details Infrastructure	Vehicle specifications with associated financial information Employment data	New vehicle specifications Fuel costs Construction costs Maintenance costs
Business parameters	Policy / Legislation Strategic goals	Profit expectations, union influences.	Availability, bulk discounts, lead time.

Table B-1: Typical management information and sources for public transport.

As can be seen, local authorities, operators, and specialist service providers all play an active role, providing and requiring information in order to carry out their function. Each role player has their own particular data requirements but much of the data is common to many of them and thus need only be gathered and stored once in a database accessible to all according to their need.

Data should pass through as few hands as possible. Thus, vehicle manufacturers for example would be expected to keep the central database updated with the latest vehicle prices and technical specifications. The local authority overseeing and sponsoring the provision of public transport is ideally placed to provide and oversee the database containing the system information. Operators and specialist suppliers, such as vehicle manufacturers, fuel companies, and contractors providing and maintaining infrastructure will provide much of the information. This implies the need for an electronic data interchange system (EDI). An EDI allows all role players to access those parts of the database of relevance to them and to add or modify data in specific sections.

An example of the application of EDI to public transport is the database operated on behalf of Guatrans by Afrigis, in Gauteng, South Africa. All the details of routes operated by several different operators and local authorities in the region are stored on a geographic information system (GIS,) which is available to all the role players using internet access. This enables improved co-ordination and planning of services.

B.4 DEMAND DATA

Irrespective of the product, defining demand for a product essentially entails determining how many people in each area are likely to buy a specific product. Potential products are defined in terms of price, place, time, and quality; thus, the market research must measure people's response to different combinations of these properties. This is often the most difficult part of the management process.

As in any other market in which some form of the product already exists, public transport market data can be split into two sections. One section describes current users and the other describes potential users of public transport. In order to deal with this, two types of market survey are undertaken. The first of these is a revealed preference survey in which actual behaviour arising out of changes to certain product characteristics is monitored. This is essentially the ridership data obtained from the public transport operators although additional information may be required and obtained through on-vehicle surveys.

The other type of survey is a stated preference study in which individuals are questioned in a structured way about their response to existing and potential products. The objective in this form of study is to establish information about people not necessarily using public transport and about desired products rather than only about existing products. In the customer service oriented, strategic logistics management approach, this form of data acquisition – market research – is vital and should be an ongoing process. Clark (2000) has done extensive work in gathering and analysing this form of public transport data for the Cape Town area.

In general and public transport planning, both these data acquisition techniques are used. However, due to the high cost of stated as opposed to revealed-preference data acquisition, the latter plays the dominant role in public transport system design. This is an area requiring urgent attention in public transport planning and operation. Such attention is starting to be given in the United States where the Transit Cooperative Research Program of the Transportation Research Board has recently published a number of reports promoting such activities. In particular, Report 50 of 1999 "A Handbook of Proven Marketing Strategies for Public Transit" provides sample questionnaires for basic market research purposes. These can and should be extended to cover product development.

In spite of its problems, revealed-preference data is nevertheless valuable for monitoring current system performance and improving existing products. This data is also useful as a measure of the performance of a proposed new system.

Irrespective of the depth of the study, data should be split temporally to best describe true demand patterns. It is normal to use four or five periods, such as AM and PM peaks and day and night off-peaks. It is however preferable to use much shorter periods so that better vehicle schedules can be established. For example, work start times are usually fairly standard and so most people might want to arrive in a particular area at about ten to eight in the morning. Very few people want to arrive at five past eight. This means that, when possible, vehicles need to be scheduled to arrive at particular times in the morning and equally, to leave at certain times in the afternoon. (This is particularly relevant when different size vehicles are operating on a route and the large ones can be scheduled to arrive, figuratively, at ten to eight and the small ones at five past eight.)

The demand data must contain information on the factors that impact on mode choice. Typical of the type of information required are walking distances to a public transport service, the acceptable number of transfers, the fare, and so on. This data will be used to compile a matrix of demand functions that are then used to estimate demand on the network, given network conditions.

Many of the data elements may not be used in one part of the planning process but may be important in another. Thus, aspects of safety and comfort are important in evaluating the best vehicles to incorporate in the fleet but individually, play little role in the basic network modelling. Some data may also be more subjective as opposed to other data be objective. For example, measuring reaction to safety and comfort changes is much more difficult than measuring reaction to fare or frequency changes. Prioni and Hensher (1999) have used the approach of developing a service quality index that is used to analyse customer responses to changes.

B.5 SUPPLY DATA

The range of information required on the supply side is far more extensive than required for the demand side, but often easier to obtain. Much of it exists already for one or another reason. For example, a great deal of the transport network information exists in the form of maps and other geographic models and is relatively static. Often information is provided, unsolicited, by suppliers anxious to sell their product. For example, manufacturers of buses and railway coaches will keep potential customers informed of developments. The fact that it is easier to obtain does not however imply that it is not as important that the correct data be kept and kept up to date.

There are also usually two aspects to the data required. The one category is specific to the immediate performance of the public transport system. Examples are vehicle and passenger capacity and at a large interchange, the walking distances required in changing lines. The other category of data refers to the management of the facility itself and incorporates operating and maintenance costs, retail revenue, and so on. These categories are used by different users and for different reasons, but are linked to the same basic piece of infrastructure, be it a road segment, a vehicle, or an interchange facility. The data is thus typically stored in separate but linked data tables so that only the required information is accessed.

B.5.1 The transport network.

In order to develop transport products, a detailed knowledge of the transport network is required. This knowledge incorporates all the geographical and operational characteristics of every element of the transport network within and bordering the study area. These elements include roads and all the associated intersections, rail lines and stations, harbours and airports and the travelled way of any other modes in operation.

The specification of the transport network as required by Emme/2 is described in detail in the Emme/2 User's Manual (INRO 1999) and is not presented here. This specification is common to most similar transportation models and is followed in developing the database used in the decision support system. Over and above broadening the scope of what constitutes a network element in Emme/2, there are also some additions to the basic data structure. These additions are specific to the public transport design process and are related to improving the value of the output data or for internal use in the computer modelling process. The Emme/2 model is unaffected by this additional data which is managed within the database. This data includes things like street names for example. This is now a standard feature of other transport planning models, such as TransCad and Visum and would thus be interchangeable between these and the public transport DSS database. The public transport planner may be interested in other information as well, and this can readily be added to an open database, such as provided in the

DSS. Examples of this additional information are the physical limitations of network links, such as the maximum weight, height and length of vehicles.

B.5.2 The supporting infrastructure

Whilst the network modelling process is little concerned with the actual form of supporting infrastructure, the public transport planning process needs to take cognisance of such infrastructure. Supporting infrastructure, in the public transport sense, includes bus stops, railway stations, park 'n ride lots, public transport vehicle depots and so on. These facilities have an impact on the network modelling in as much as they may be capacity limited or have mode restrictions and in that it is desirable to include them in other planning considerations. In the overall planning process, they also influence customer satisfaction, absorb funds, and have the potential to generate funds over and above those arising directly from public transport activities.

B.5.3 Vehicle specifications for the existing fleet

An important part of the public transport business is its vehicle fleet, which represents the production capacity of the business. The fleet is often made up of vehicles belonging to several different operators. The vehicles themselves may be different in many respects and have quite different operating characteristics. A detailed knowledge of the fleet is necessary to ensuring the best use of the vehicles. The central authority needs to know how many vehicles of each type are available and the time and distance based costs of these vehicles.

There are several other reasons for needing such data. The transport authority essentially buys services from the independent operators and needs to have a good estimate of the realistic costs of operating each type of vehicle so that it can evaluate the claims of the operators. There is also the possibility of using central maintenance works to look after the vehicles of smaller operators. Only by knowing what types of vehicle and the ages of the vehicle can the establishment and operation of such central facilities be evaluated.

In order to determine the operating costs of the different vehicles, operators have to provide some financial information. This is the most sensitive of all the data requirements. In a competitive business environment, no operator wants to let anyone else know his actual costs and profits. Nevertheless, if public transport operators are to work together in promoting their industry, some information must be made available to the central management function so that budgeting can be carried out. Whilst a complete cost schedule for every vehicle type owned by each operator will be very valuable, it is not vital for system management. Each operator will however, be required to determine the time and distance based costs for each vehicle type using some method or another and to keep this data up to date. The central authority may distribute the cost schedule described in Chapter 7 to the operators who will maintain it themselves, thus keeping some degree of financial privacy, providing only the main results. The authority can use data obtained from other sources to develop estimates for each vehicle class as a comparison.

B.5.4 Vehicle specifications for new vehicles

At any time, the fleet will comprise a range of vehicles, some new, some old. The older ones have to be replaced at some stage for various reasons, ranging from pure economics through legal requirements to customer service motivations. Suppliers of new vehicles, be they buses or railway coaches, will be likely to keep a transport authority informed of their latest products and their performance. This information is valuable for planning new vehicle acquisitions. Technology is constantly improving the fuel economy, safety, and environmental friendliness of vehicles. Thus, in a scenario where one or other characteristic is an important parameter of the system design, it may prove worthwhile to replace certain sections of the fleet as soon as possible. Information on the latest available vehicles should thus be included in the planning model and will indicate which vehicles should be replaced and with which new ones. This is from the overall planning perspective, not the operator perspective, as we are interested in the system performance. The essential data will be stored using the same format as for the existing vehicles.

B.5.5 Employment data

In South Africa, job creation and affirmative action are both significant criteria in awarding government contracts. When public transport is provided by a number of operators under contract to a central authority, as is to happen in South Africa, individual operators need to provide employment information so that their tenders can be evaluated. Typically, it is necessary for each operator to provide information on the number, sex, race, and function of employees and minimum and maximum wages. Whilst not specifically modelled in this DSS, there is no reason why this information could not be included in a contract allocation model. It should thus be considered for inclusion in the DSS database.

B.5.6 Specialist supplier information

The financial performance of the public transport system is dependent on the cost of the raw materials needed to operate. For example, most road-based vehicles are dependent on the oil price, which constantly fluctuates, affecting operating costs. Historical performance appraisal and budget projections rely on some knowledge of these costs. There may also be economy of scale or alternative fuel opportunities available to the industry as a whole. Fuel costs are only one aspect of the external costs associated with the public transport system. For example, the fixed infrastructure belonging to the transport authority must be maintained or replaced and new infrastructure must be built. Planning for these events requires the necessary data. Most of this type of data is facility specific.

There are many auxiliary systems associated with the public transport system. The suppliers of information systems, such as maps and signs, of ticketing and control barrier systems are all examples of such suppliers. A record needs to be kept of who they are, what they do, their current products of relevance and the associated costs. Much of this information is incidental to the day to day operation and management of the public transport system but will be useful when strategic planning exercises are undertaken. Using the data for equipment and technology not currently in the system enables an evaluation of possible savings. For example, a ticket system manufacturer may claim a reduction in the boarding time for vehicles fitted with his equipment compared with the current equipment. It may prove justified to replace the equipment as new vehicles are brought into service. These comparisons can only be made if data is available and data does not always come to hand just when needed but often lies around for months or even years before being useful.

B.6 STRATEGIC DATA

We have looked at the information requirements for the demand and supply sides of the public transport system. There is however, a third category of information that is necessary to the making of management decisions, the business parameters. This information steers all decision-making.

In the past, it has been common to measure public transport system performance in terms of internal operating efficiencies such as those listed by Vuchic (1981.) This is no longer an adequate approach and additional, external measures need to be taken into account. The TCRP Report 53, (1999,) suggests that it is necessary to move from measures of efficiency to measures of "impact" and from output to "outcome." This is a more market-oriented approach, which in the public transport industry may include social, economic and environmental issues, external to the public transport operations specifically.

Given this line of thinking, a range of long-term goals and immediate objectives needs to be determined by consensus of all role players. These role players include the public transport users and operators, the environmentalists, those responsible for social welfare, economic development and, urban planning. Those involved in other aspects of transport infrastructure use, which includes major role players in the commercial and industrial sectors, also need to be included. These goals and objectives result in a specification of the business parameters, which have two properties distinguishing them from the other forms of information discussed so far. Firstly, many of them have a range, rather than an absolute value. Secondly, they have a relative importance with respect to each other. Thus, each parameter must be assigned a lower bound, an upper bound, a target value and a rank or weight with respect to the other parameters.

To demonstrate this, let us examine a simple example, that of profit. We own and work in a business. The choices we have are that we can make more money but then we must work longer hours, or we can work fewer hours and make less profit. What is the minimum amount of profit that is acceptable? What profit would we like to make? Is there an upper limit on the achievable profit and if so, what is it? Which is more important, our free time or the money? Every business owner has to make such decisions and come to some decision. Quite often, the actual work hours are limited by some other factors such as the size of the market or labour laws. These external factors may dictate the boundary values.

In the public transport business in which there are many active participants, and even more interested parties, there are many such decisions. Environmental legislation may set pollution level maxima. When these levels are approached, measures are taken to limit additional production of the pollutant, which can usually only be achieved by spending money on new or additional technology. Politicians may have promised cheap transport to all, setting a maximum fare level. Operating the system at this fare level may be difficult or even impossible without external subsidy, which comes from taxpayer money. Poorer quality service may be the answer to this but will not support other goals of providing a higher minimum standard of service.

It is impossible to present an exhaustive list of such parameters but there are several of them, which are relevant in South Africa. In addition to other legislation, the South African government White Paper on Transport Policy of 1996 and subsequent related documents have provided a range of target values. Not all of these values are necessarily the best ones, but serve as a starting point. Each should be subjected to re-evaluation for the local conditions.

Setting of these business parameters is never easy and is that much more difficult when linked to a public service. As was noted in Chapter 3 there are techniques for dealing with developing consensus on the issues of importance that are vital to the implementation of the planning process as well as the ongoing operation.

B.7 OUTPUT DATA

The management process output data is as important as the input data. There are two main categories of data in this case – process data and promotional information aimed at the customer and potential customer.

B.7.1 Process data

The process data is that which defines the actual functioning of the system. This includes route and interchange specifications, tender allocations, budgets, and information on future changes to the system and the timing of their implementation. It is primarily in this area that the DSS is of use, providing route definitions, vehicle allocation details, and interchange information. These include both technical and financial aspects. These are dealt with elsewhere in the dissertation and are thus not discussed in any further detail here.

B.7.2 Promotional information

As in any other business, the main asset of the public transport business is the customer. The customer must be kept informed of the products available at all times, in a manner that is comprehensible to the majority of customers and potential customers. Much of this information is gleaned directly from the process data, timetables, and fare structures for example. Some data must however be gathered and presented as part of separate promotional activity. For example, the public transport business must be able to tell its customers what the benefits are of public transport over the competition, the private car. The development of promotional data is a marketing matter and beyond the scope of this work. It is however, worth pointing out again that as part of the strategic logistics management approach the marketing effort must not be neglected in favour of the technical issues, the two belong hand in hand.

B.8 REFERENCES

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APPENDIX C.

NETWORK MODELLING TERMINOLOGY

Most of the network modelling terms used are accepted as standard, but for clarity this appendix defines some of the terminology specifically relevant to the modelling process described in this dissertation.

C.1 BASIC NETWORK ELEMENTS

Network models typically comprise a limited number of basic elements used to describe all components of the network. The most common of these are defined here.

Zone	A subdivision of the area to be modelled, usually but not necessarily of more or less homogeneous land use type, such as residential, educational, industrial or commercial.
Centroid nodes	The hypothetical centre of a zone where all trips from and to the zone originate and terminate.
Regular nodes	A regular node is a point representing a connection between two or more links.
Link	Typically, a road or rail segment. Each direction requires a separate link but the link may comprise more than one lane of similar attributes. Lanes in the same direction but with different attributes must be specified as separate, parallel links.

C.2 NETWORK MODELLING TERMS

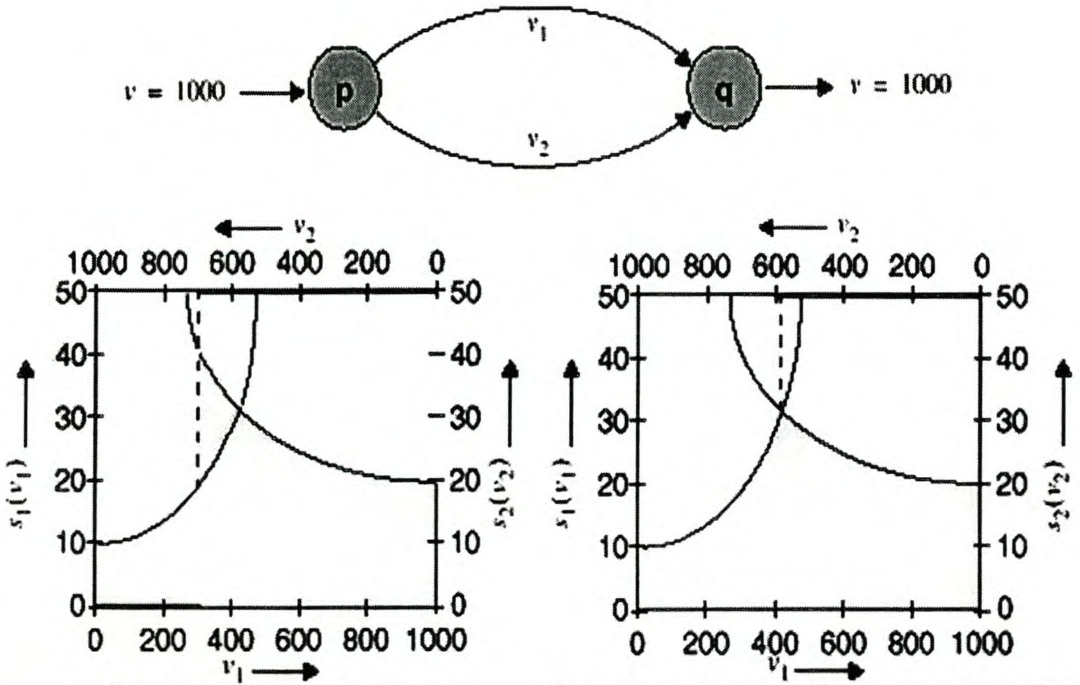
There are also a number of other terms which are used.

Equilibrium	A condition in which no transport network user can improve his or her generalised-cost of travel by changing routes.
Generalised-cost	An estimate of total cost trip cost derived by summing diverse cost components. e.g. Travel time + Out of pocket trip cost.
Volume delay function	A mathematical representation of the travel time on a link or through a junction as a function of the number of vehicles using the element and the vehicle capacity of the element.
Assignment	The mathematical process of allocating trips to the network. In this case, in accordance with the equilibrium concept.
Single-class assignment	An assignment in which all users assigned to the network are assumed to perceive all link attributes in the same way.
Multi-class assignment	An assignment process in which different classes of user see the same link travel times but perceive other network attributes differently, resulting in different route choices.
User attribute	Each network element has a number of attributes that describe it, some of which are required by the modelling package. Each element may also have attributes that are relevant only to the particular planning process. These project specific attributes are determined by the planner and are known as "user attributes."

APPENDIX D.

THE EQUILIBRIUM ASSIGNMENT CONCEPT

This equilibrium concept as used in the public transport network design process is illustrated in , which has been copied directly from the Emme/2 User's Manual (INRO 1999) and modified only to include the meaning of the symbols.



Assignment not in equilibrium.

Assignment in equilibrium. Area under volume-delay curves is minimized.

Where: v = traffic volume on link.
s = travel time as a function of traffic volume on link.

Figure D-1: Diagrammatic representation of the equilibrium concept.
(From Emme/2 User's Manual 1999, Figure 6-1, pg. 6-7.)

Essentially, the equilibrium assignment process seeks to find the link volumes for every link on the network such that the travel time for each origin destination pair cannot be improved upon by choosing a different path. This amounts to minimising the area under the combined volume delay curves. This is not the same as minimising the total travel time on the network which gives system optimal flow rather than user optimal flow.

APPENDIX E.

CREATING THE EXPRESS AND REGULAR DEMAND MATRICES.

Given:

Public transport demand matrix = mf02.

Create "Shortest path matrix" mf07.

Create a dummy trip matrix, ms02 with a value of 1.

Create a volume delay function fd45 = length (If such a function does not already exist.)

Set the volume delay function of all links to = 45

Run a single-class assignment with ms02 as the demand matrix. Save the travel times to mf07. The entries in this matrix reflect the shortest possible path between origin destination pairs.

Create mf10 and mf11 – working matrices. (mf10 will become the regular demand matrix.)

Then: Temporary matrix mf11 = mf02

Constraint matrix = mf07

Constraint = 0,5,exclude Only O-D pairs with a distance between them of more than 5 km.

Express demand matrix mf09 = mf11

Constraint matrix = mf11

Constraint = 0,20,exclude Only O-D pairs with more than 20 trips will be included in mf09.

Create the transpose of mf09:

mf10=mf09' This enables acquiring the reverse trips.

Add reverse trips to mf09:

mf09 = mf09+mf02

Constraint matrix = mf10

Constraint = 0,19,exclude Mf09 and mf02 will only be added for those O-D pairs where the value of mf10 is greater than 19. This includes only the reversed pairs defined when mf09 was first created.

And:

Regular matrix mf10 = mf02-mf09

Constraint matrix = none.

APPENDIX F.

ENHANCING THE NETWORK MODEL RESULT DISPLAY

The Emme/2 network calculator is used to set a user attribute or an extra link attribute to a code reflecting the volume using each link. It is preferable to set the codes to correlate to suitable colour indices for graphical representation. This can be achieved in the following way, assuming only three partitions.

Set UL3 = 4 — ((Volau+Volaur)>200) — ((Volau+Volaur)>1000)

This will result in all links with total two-way volumes of less than 200 trips being given a UL3 value of 4, corresponding to the colour blue. Links with a total two-way volume of between 201 and 1000 will have a UL3 value of 3, green, and links with a total volume of over 1000 a code of 2 which is the colour index for red. UL3 is then set as the source of the colour index when plotting the demand volumes or times. Similar forms can be derived for other methods of display, for example when either of the directions meets a certain criteria, one can use the form:

4-((volau>800).or.(volaur>800))-((volau>200).or.(volaur>200))

Where there are a number of different modes, the above colour-code setting process is repeated for each mode, with its own volume categorisation, and specifying the specific mode in the calculation criteria.

When displaying the graphic, using module 6.12, the centroids can be excluded using the link selection:

Enter: Selected link types or attributes (from, to)

=ci=0

=and cj=0

Link exclusion can be carried further by marking those links where the total demand is too small to justify a service but are in use because there are no alternatives for the users. This is done by setting ul2 = ul2 + (volau + volaur>12) for example, which will give a value of ul2 = 2 for all links where the total two-way demand exceeds 12.

Using the graphic display of the assigned demand, module 6.12, and requiring the display to reflect the links coloured according the user attribute results in a graphic showing the various service categories – i.e. feeder services, bus services, potential rail or dedicated ways and so on. An example of such a result is shown in Figure 9-4. The places where the colour changes are worthy of consideration as park 'n ride facilities as well as being natural interchange points and thus warranting evaluation as "transit centres."

APPENDIX G.

EXPANDED EXAMPLE OF ROUTE EXTRACTION PROCESS.

The following pages contain the complete printout of the route extraction process for the network in **Figure 5-1**. The process has been carried out by hand in a spreadsheet that is included on the compact disc accompanying the dissertation as:

CD:\MSExcel\MiniExample**RtEg.xls**

Notes:

The example initially assumes a minimum route demand of 20 trips.

Each link has a length of 1 km for the example.

The return link trips are assigned to the forward route in the ratio of the line capacity to the forward trips remaining before the route is declared. When the capacity on a link exceeds the demand, the ratio is limited to one

The link travel time in each direction is also recorded and summed for each route. This is included in the example.

Without an origin-destination demand matrix, it is not possible to establish the number of transfers required.

The link selection sequences:

The Iteration column contain the iteration number and the order of link selection.

After the last iteration, i.e. iterations 3 and 4, all links have zero trips remaining.

Network data Extraction process steps

I	J	Total demand	Trips remaining	Iteration 1	Trips remaining	Iteration 2	Trips remaining	Iteration 3	Iteration 2a	Trips remaining	Iteration 3a	Trips remaining	Iteration 4
1	4	100	100	4	0		0			0		0	
2	4	90	90		90	3	0		3	10		10	1
3	4	70	70		70		70	4		70	4	0	
4	1	20	20		0		0			0		0	
4	2	20	20		20		0			2		2	
4	3	60	60		60		60			60		0	
4	5	260	260	1	160	1	70	3	1	80	1	10	2
5	4	100	100		62		27			31		4	
5	6	80	80		80	2	-10		2	0		0	
5	7	180	180	2	80		80	1		80	2	10	3
6	5	20	20		20		0			0		0	
7	5	80	80		36		36			36		5	
7	8	100	100	3	0		0			0		0	
7	9	80	80		80		80	2		80	3	10	4
8	7	40	40		0		0			0		0	
9	7	40	40		40		40			40		5	

1340 Total passenger-kilometres on network.

G.1 THE RESULTS:

Route 1:
Node sequence: 1 4 5 7 8 7 5 4 1
Total length: 8 km
Min trips = 100 In forward direction.
Min remaining trips > 0
Capacity = 100

					a	***b***	***c***	***d***	See below:
Link:	1-4	4-5	5-7	7-8	8-7	7-5	5-4	4-1	
Passenger Km =	100	100	100	100	40	44	38	20	**542**

a: Pass.Km = 100*40/100 = 40 i.e. capacity * reverse trips / outstanding trips
b: Pass.Km = 100*80/180 = 44
c: Pass.Km = 100*100/260 = 38
d: Pass.Km = 100*20/100 = 20

Route 2:
Node sequence: 2 4 5 6 5 4 2
Total length: 6 km
Min trips = 80 In forward direction.
Min remaining trips > 0 10 Not acceptable as minimum is 20 trips, so select next lowest link 2-4, 90 trips.
Capacity = 90

Link:	2-4	4-5	5-6	6-5	5-4	4-2	
Passenger Km =	90	90	80	20	35	20	**335**

Route 3:
Node sequence: 3 4 5 7 9 7 5 4 3
Total length: 8 km
Min trips = 70 In forward direction.
Min remaining trips > 0 10 Not acceptable as minimum is 20 trips, so select next lowest, link 5-7, 80 trips.
Capacity = 80

Link:	3-4	4-5	5-7	7-9	9-7	7-5	5-4	4-3	
Passenger Km =	70	70	80	80	40	36	27	60	**463**

Total passenger km = 542 + 335 + 463 = 1340 as expected.
Total route length = 8 + 6 + 8 = 22

If the 20 trip minimum is reduced to 10, the first route remains the same but the other routes become:

Route 2a:

Node sequence: 2 4 5 6 5 4 2
Total length: 6 km
Min trips = 80 In forward direction.
Capacity = 80

Link:	2-4	4-5	5-6	6-5	5-4	4-2	
Passenger Km =	80	80	80	20	31	18	**309**

Route 3a:

Nodes sequence: 3 4 5 7 9 7 5 4 3
Total length: 8 km
Min trips = 70 In forward direction.
Capacity = 70

Link:	3-4	4-5	5-7	7-9	9-7	7-5	5-4	4-3	
Passenger Km =	70	70	70	70	35	31	27	60	**433**

Route 4:

Nodes sequence: 2 4 5 7 9 7 5 4 2
Total length: 8 km
Min trips = 10 In forward direction.
Capacity = 10

Link:	2-4	4-5	5-7	7-9	9-7	7-5	5-4	4-2	
Passenger Km =	10	10	10	10	5	5	4	2	**56**

Total passenger km = 542 + 309 + 433 + 56 = 1340 as expected.
Total route length = 8 + 6 + 8 + 8 = 30

G.2 COMMENTS:

- As can be seen, a further reduction in the minimum remaining trips will introduce additional lines.
- The total route length is increased.
- In this example, increasing the minimum remaining trips will have no impact.

APPENDIX H.

THE "TRANSIT GRID" EXAMPLE

The route extraction process can be practically demonstrated to work effectively on simple networks but is less clearly effective in complex networks. It is also primarily intended for public transport planning at the urban level, not the local level. Nevertheless, the process can be demonstrated to produce useful results, even in a grid network. To demonstrate this, an analysis of a small grid network, in which a route configuration generated by this method, is compared against a "conventional" grid of public transport lines. The full study is contained on the CD accompanying this dissertation in the "Transit" sub-folders.

H.1 THE BASE NETWORK

The base network for the example presented is a simple grid with twelve centroid nodes numbered 100 to 1200 and twenty-one regular nodes numbered 1 to 21 as shown in Figure H-1.

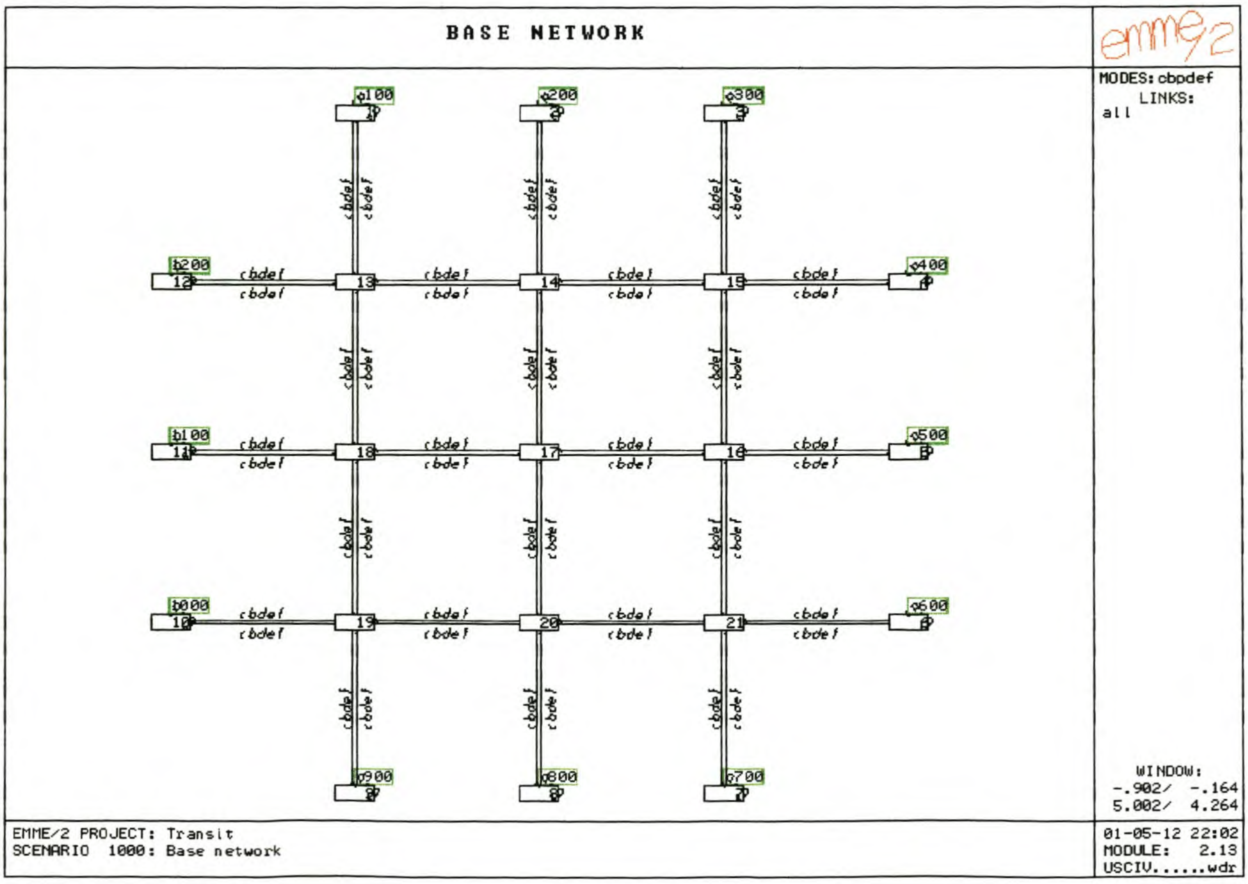


Figure H-1: The base network.

The centroid nodes link to the regular nodes via short, two-way, pedestrian links. All other links are one kilometre long and allow a number of transit modes, each mode representing a different transit line configuration.

H.2 THE DEMAND MATRIX

The demand matrix is shown in Table H-1. This is an entirely arbitrary matrix constructed for the purpose of example.

O\D	4	5	6	7	8	9	Sum	Required
1	10	58	57	20	25	30	200	200
2	8	43	43	15	19	22	150	150
3	3	17	17	6	8	9	60	60
10	10	58	57	20	25	30	200	200
11	5	28	30	10	12	15	100	100
12	4	26	26	9	11	14	90	90
Sum	40	230	230	80	100	120	800	800
Required	40	230	230	80	100	120	800	

Table H-1: Transit example demand matrix.

H.3 THE AUTO-ASSIGNMENT RESULTS

The example is highly simplified in that only one demand matrix has been used. The focusing process is thus not based on interaction between public and private transport. There is however, a volume delay function common to all links, which has been used in the focusing process. The assignment result after four focusing steps is shown in Figure H-2. In this particular example, the focusing process has a limited impact on the link volumes when the link volumes are examined. A comparison in link volumes between the focused and unfocused scenarios is shown in Figure H-3. When the assignment results are subjected to the route extraction process however, measurably different results are obtained as will be demonstrated.

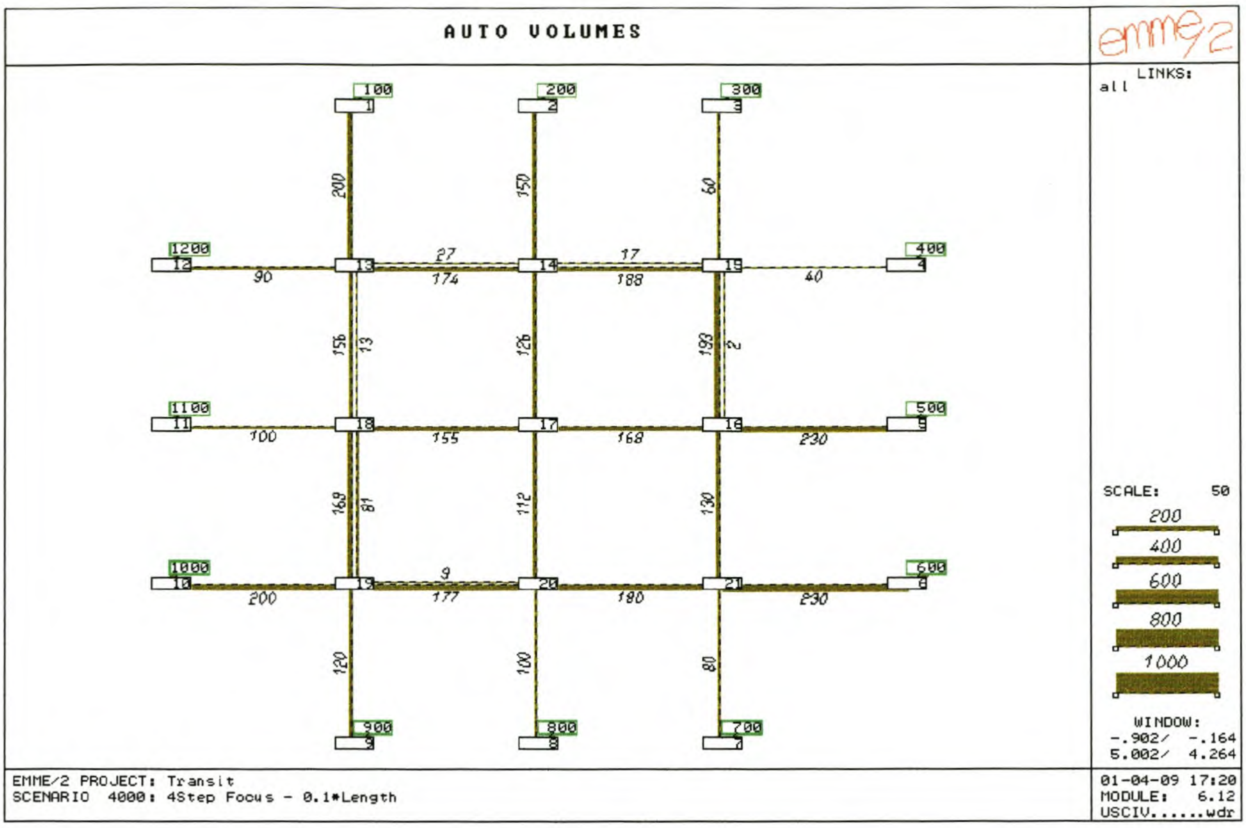


Figure H-2: Assignment results after 4 focusing steps. Using a step capacity of 12 passengers.

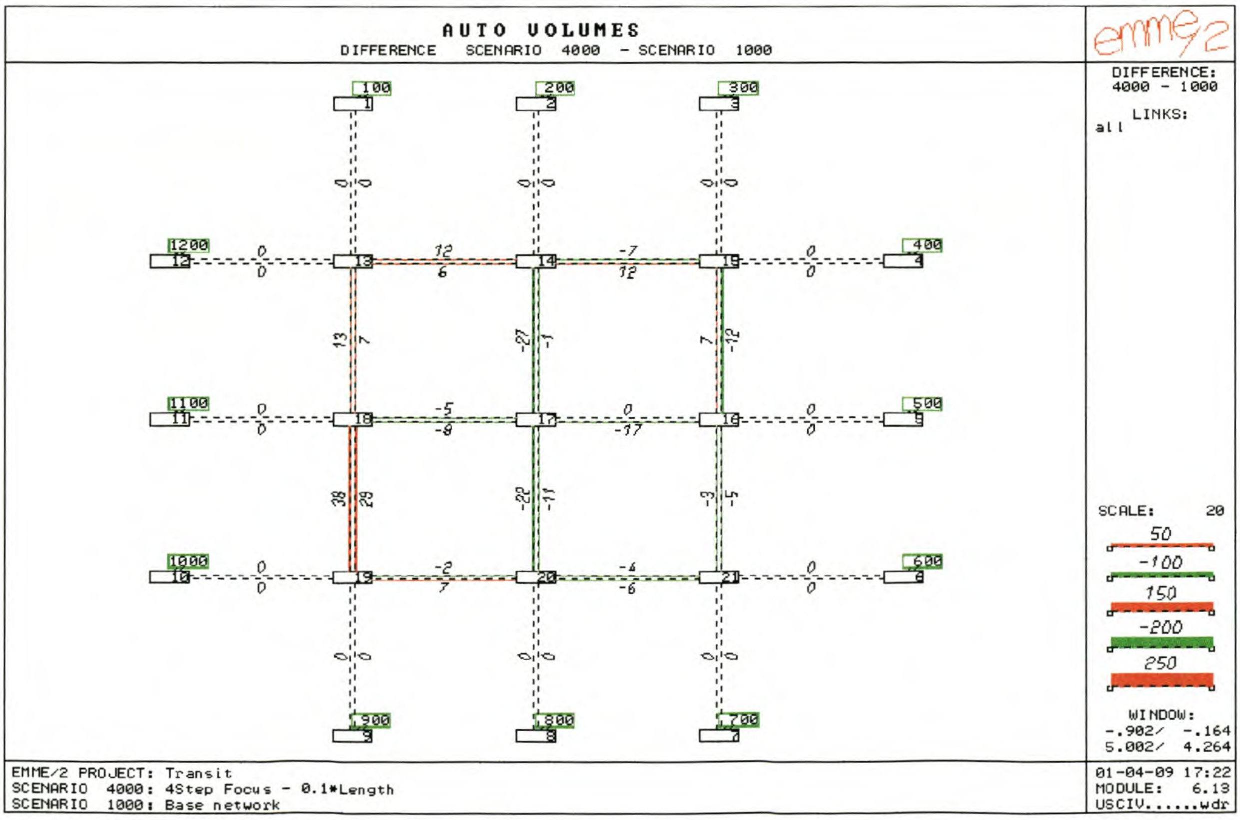


Figure H-3: Comparison between focused and unfocused assignment link volumes.

H.4 THE TRANSIT LINES

In order to cover all origin-destination pairs in the example grid, at least six lines are necessary unless backtracking is allowed. The question to be answered is; what route configuration achieves the best performance in terms of transfers, vehicle-kilometres, vehicle utilisation etc? Obviously, the number of transfers can be reduced to zero by providing a service between every origin-destination pair between which there is demand. This is extremely inefficient if adequate service frequency is to be maintained and requires thirty-six lines given the demand pattern in this specific example and sixty-six lines for the general case for this network. In the example, only six lines have been used in any of the configurations although different route extraction program parameters will result in different numbers of lines.

The transit lines have been developed on the basis that all demand must be satisfied. The lines have then been analysed on various bases given that only one vehicle type may be used on a line:

- The minimum line frequency.
- A minimum of four departures per hour.
- The minimum possible departures per hour.
- The available vehicle types.
    - One vehicle type only – total capacity of 60 passengers.
    - Two vehicle types, total capacities of 60 and 18 passengers respectively.

Four line configurations are tested:

- A basic grid configuration.
- The route extraction results after focusing of the demand.
- A manual modification of the route extraction results after focusing. (Small modifications to the final route set will sometimes produce improved route definitions and in this case, such a modification results in reduced transfers at the expense of other factors.)
- The route extraction results based on the unfocused assignment.

In each case, the initial line capacities are modified manually in repeated Emme/2 transit assignments to ensure that the peak load-factor does not exceed 1 and the initial and final line capacities are reported.

H.4.1 Line configuration 1: Grid configuration.

These lines, following the grid format, are manually derived based on the link volumes arising in the unfocused assignment. Table H-2 shows the line path and first estimate of the capacity required for each line. The capacity must at least equal the greater of the end link demands, irrespective of the demand on the other links.

ROUTES

Route	Mod	Capacity	Length	Pass.km	Utilisation	Time	Node_Sequence
1	b	200	8.00	—	—	—	113 18 19 9 19 18 13 1
2	b	152	8.00	—	—	—	2 14 17 20 8 20 17 14 2
3	b	186	8.00	—	—	—	3 15 16 21 7 21 16 15 3
4	b	176	8.00	—	—	—	12 13 14 15 4 15 14 13 12
5	b	230	6.00	—	—	—	11 18 17 16 5 16 17 18 11
6	b	230	8.00	—	—	—	10 19 20 21 6 21 20 19 10
Totals:		1174	48.00	—	—		

Group	Min Vol	Min Remain	Min Length	Min Util	Express
Road	0	60	4	0	

Table H-2: The initial route definitions for the grid network.

H.4.2 Line configuration 2: Route extraction on focused demand.

Table H-3 shows the results of the route extraction process for the focused demand assignment and the route extraction parameters us in the process.

ROUTES

Route	Mod	Capacity	Length	Pass.km	Utilisation	Time	Node_Sequence
1	b	230	10.00	1031	0.45	14.99	1 13 14 15 16 5 16 15 14 13 1
2	b	230	8.00	796	0.43	12.03	10 19 20 21 6 21 20 19 10
3	b	169	8.00	629	0.47	9.08	12 13 18 19 9 19 18 13 12
4	b	168	10.00	633	0.38	11.13	11 18 17 16 21 7 21 16 17 18 11
5	b	150	8.00	488	0.41	8.64	2 14 17 20 8 20 17 14 2
6	b	60	4.00	100	0.42	4.01	3 15 4 15 3
Totals:		1007	48.00	3677	0.42		

Group	Min Vol	Min Remain	Min Length	Min Util	Express
Road	0	60	4	0	

Table H-3: Results of route extraction process for the focused network.

H.4.3 Line configuration 3: Manually modification of configuration 2.

Line configuration 3 is derived from line configuration 2. Examination of the demand matrix and the lines suggests that the number of required transfers can be significantly reduced by by swapping the destinations of routes 1 and 2 to produce the lines shown in Table H-4.

ROUTES

Route	Mod	Capacity	Length	Pass.km	Utilisation	Time	Node_Sequence
1	b	230	12.00	—	—	—	1 13 14 15 16 21 6 21 16 15 14 13 1
2	b	230	10.00	—	—	—	10 19 20 21 16 5 16 21 20 19 10
3	b	169	8.00	629	0.47	9.08	12 13 18 19 9 19 18 13 12
4	b	168	10.00	633	0.38	11.13	11 18 17 16 21 7 21 16 17 18 11
5	b	150	8.00	488	0.41	8.64	2 14 17 20 8 20 17 14 2
6	b	60	4.00	100	0.42	4.01	3 15 4 15 3
Totals:		1007	52.00	—	—		

Group	Min Vol	Min Remain	Min Length	Min Util	Express
Road	0	60	4	0	

Table H-4: Manually modified routes based on those in Line configuration 4: Route extraction on unfocused demand.

This line configuration is derived using the route extraction process on the results of the demand assignment when no focusing takes place. The route definitions are shown in Table H-5.

ROUTES

Route	Mod	Capacity	Length	Pass.km	Utilisation	Time	Node_Sequence
1	b	230	10.00	1013	0.44	14.60	1 13 14 15 16 5 16 15 14 13 1
2	b	230	8.00	801	0.44	12.04	10 19 20 21 6 21 20 19 10
3	b	185	12.00	809	0.36	13.70	12 13 18 17 16 21 7 21 16 17 18 13 12
4	b	152	8.00	549	0.45	8.93	2 14 17 20 8 20 17 14 2
5	b	131	6.00	403	0.51	6.37	11 18 19 9 19 18 11
6	b	60	4.00	100	0.42	4.01	3 15 4 15 3
Totals:		988	48.00	3675	0.44		

Group	Min Vol	Min Remain	Min Length	Min Util	Express
Road	0	60	4	0	

Table H-5: Results of route extraction process for the unfocused network.

H.5 THE TRANSIT-ASSIGNMENT RESULTS

The results have been obtained using two methods:

- The minimum possible number of transfers for the origin-destination pairs has been determined manually given the line definitions. The minimum total number of transfers required for each configuration has then been determined with the aid of a spreadsheet.
- The Emme/2 Transit Assignment has been used.

The results are based on various configuration criteria. The first of these is as follows:

- There must be a minimum of four vehicles per hour.
- There are only two vehicle types available.
- A route can only have one vehicle type at a time.

H.5.1 Transfers

The minimum number of transfers, determined for each configuration using a spreadsheet, is shown in Table H-6.

Configuration No.	Minimum Transfers
1	910
2	881
3	739
4	954

Table H-6: Minimum transfers required for each line configuration.

As can be seen, configuration 3, the manually modified version of the route extraction results based on the focused demand assignment, produces the lowest minimum possible transfers. The unmodified route extraction process results offer a small improvement over a grid configuration whilst the results based on the unfocused demand result in an increase in the number of transfers. The minimum number of transfers is not always achieved in the assignment process as will be seen later. This is because the reduction in transfers is sometimes accompanied by an increase in journey distance and thus time. There is also a tendency for increased customer service levels to be accompanied by increased costs.

H.6 TRANSIT ASSIGNMENT RESULTS

In the spreadsheet model, the results are clear and easily repeated. In Emme/2 however, there are an infinite number of ways of assigning the demand to the potential routes. This is because Emme/2 uses the concept of strategies in the assignment process and each variation in the strategy parameters produces different assignment results. The results shown here are based on the following:

Boarding time = 0.5 min

Wait time factor = 0.3 This implies that the schedule is fixed and regular. Initial boardings will have minimal waiting time. The objective is to demonstrate the potential reduction costs and the number of transfers required.

Wait time weight = 0.5 Since the schedule if known, waiting time is not heavily penalised.

Auxiliary transit time weight = 0.0 Not relevant in the example.

Boarding time weight = 1.0

For each of the route configurations, the minimum number of transfers has been determined using the demand matrix and the line configurations. The results are shown in Table H-7 with a key to the configuration codes used given in Table H-8.

Configuration	No. Vehs.	Load factor	Transfers	Lines/ pass.	Pass.hrs	Pass.km	OpCost	Energy
C1R1	7	0.30	910	2.14	166.7	3642	1560	1152
C1R2	7	0.36	910	2.14	176.4	3642	1400	967
C1R3	7	0.30	910	2.14	166.7	3642	1560	1152
C2R1	8	0.30	881	2.10	164.8	3642	1650	1163
C2R2	8	0.41	881	2.10	191.8	3717	1400	875
C2R3	8	0.32	881	2.10	164.8	3642	1578	1122
C3R1	10	0.26	808	2.01	158.2	3642	1960	1134
C3R2	9	0.34	808	2.01	185.8	3642	1600	1014
C3R3	10	0.27	808	2.01	158.2	3642	1888	1295
C4R1	8	0.32	954	2.19	171.5	3642	1600	1106
C4R2	8	0.41	954	2.20	197.1	3745	1400	875
C4R3	8	0.34	954	2.19	171.5	3642	1528	1064

Table H-7: Results of the analysis of various route configurations under different conditions. See Table H-8 for key to configuration codes.

Key	
C1	Grid configuration.
C2	Route extraction on focused demand.
C3	Manually modified route extraction on focused demand.
C4	Route extraction on unfocused demand.
R 1	Four vehicles per hour minimum. Only one vehicle type available.
R 2	One vehicle per hour minimum. Only one vehicle type available.
R 3	Four vehicles per hour minimum. Two vehicle types available.

Table H-8: Key to configuration codes for results analysis in Table H-7.

As can be seen, most route configurations offer an advantage in some respect or another. Which of these configurations is chosen will depend on the overall design policy. Since the policy upon which this example is based was a minimum service frequency of four trips per hour, configurations R2 should not be considered. They are however provided to demonstrate that when the frequency is flexible, considerable improvements can be achieved. However, the weight must lie with the relative value of customer service, operating costs and energy consumption. As can be seen in Table H-7, configurations C2R1 and C2R3, the route extraction program results for the focused demand, offer competitive performance on all accounts, although not the best in any.

Of course, different route extraction and Emme2 assignment parameters produce different values from those presented here. For example, increasing the waiting time penalty in the Emme/2 assignment increases the number of transfers made in an effort to reduce overall travel time. Reducing the minimum remainder in the route extraction program increases the number of lines. This reduces the number of transfers but increases the overall cost. However, given that there are alternative ways of analysing and interpreting the route extraction program results, this example has served to demonstrate that in a very simple grid network, the program can produce results which are worthy of consideration.

APPENDIX I.

RESULTS OF RESOURCE ALLOCATION PROCESS.

This result set shows the main part of the data output for the Transit example. The original is in the file Transit.lgr on the accompanying CD. This particular configuration is for the multi-period fleet constrained case with vehicle height restrictions on one route.

DU	1	TOTALCOST	10234.8	HO(PM)	3
DO	0	MCOST	1.00E-03	MINDEM(AM)	60
FU	1	ENFSUBS	0	MINDEM(PM)	60
FO	0	MAXSUB	1	PFREQ(AM)	1
TU	0	NOROUTES	12	PFREQ(PM)	1
TO	1	TOTTIME	8	PCOST(AM)	1
SU	0	MAXCAP	54	PCOST(PM)	1
SO	1	NOMODES	2	PERIOD(AM_1)	1
DV	0	TOTPASSKMXK	21.4524	PERIOD(AM_2)	1
MAXDIFF	0	MINCAP	12.6	PERIOD(AM_3)	1
WCOST	1	START_TIME(AM)	7	PERIOD(AM_4)	1
NETCOST	-2.819523	START_TIME(PM)	16	PERIOD(AM_5)	1
ENFSTOCK	1	TLENGTH(AM)	4	PERIOD(AM_6)	1
NOPERIODS	2	TLENGTH(PM)	4	PERIOD(PM_1)	2
TOTREVENUE	13054.32	HO(AM)	3	PERIOD(PM_2)	2

PERIOD(PM_3)	2	DEMANDU(PM_1, PM)	0	DESCAP(AM_5, AM)	162
PERIOD(PM_4)	2	DEMANDU(PM_2, PM)	0	DESCAP(AM_6, AM)	63
PERIOD(PM_5)	2	DEMANDU(PM_3, PM)	5.2	DESCAP(PM_1, PM)	237.6
PERIOD(PM_6)	2	DEMANDU(PM_4, PM)	6	DESCAP(PM_2, PM)	237.6
DEMAND(AM_1, AM)	230	DEMANDU(PM_5, PM)	0	DESCAP(PM_3, PM)	163.8
DEMAND(AM_2, AM)	230	DEMANDU(PM_6, PM)	0	DESCAP(PM_4, PM)	162
DEMAND(AM_3, AM)	169	DEMANDO(AM_1, AM)	7.6	DESCAP(PM_5, PM)	162
DEMAND(AM_4, AM)	168	DEMANDO(AM_2, AM)	7.6	DESCAP(PM_6, PM)	63
DEMAND(AM_5, AM)	150	DEMANDO(AM_3, AM)	0	TOTCAP(AM_1, AM)	264
DEMAND(AM_6, AM)	60	DEMANDO(AM_4, AM)	0	TOTCAP(AM_2, AM)	264
DEMAND(PM_1, PM)	230	DEMANDO(AM_5, AM)	12	TOTCAP(AM_3, AM)	182
DEMAND(PM_2, PM)	230	DEMANDO(AM_6, AM)	3	TOTCAP(AM_4, AM)	180
DEMAND(PM_3, PM)	169	DEMANDO(PM_1, PM)	7.6	TOTCAP(AM_5, AM)	180
DEMAND(PM_4, PM)	168	DEMANDO(PM_2, PM)	7.6	TOTCAP(AM_6, AM)	70
DEMAND(PM_5, PM)	150	DEMANDO(PM_3, PM)	0	TOTCAP(PM_1, PM)	264
DEMAND(PM_6, PM)	60	DEMANDO(PM_4, PM)	0	TOTCAP(PM_2, PM)	264
DEMANDU(AM_1, AM)	0	DEMANDO(PM_5, PM)	12	TOTCAP(PM_3, PM)	182
DEMANDU(AM_2, AM)	0	DEMANDO(PM_6, PM)	3	TOTCAP(PM_4, PM)	180
DEMANDU(AM_3, AM)	5.2	DESCAP(AM_1, AM)	237.6	TOTCAP(PM_5, PM)	180
DEMANDU(AM_4, AM)	6	DESCAP(AM_2, AM)	237.6	TOTCAP(PM_6, PM)	70
DEMANDU(AM_5, AM)	0	DESCAP(AM_3, AM)	163.8	FREQ(AM_1, AM)	4
DEMANDU(AM_6, AM)	0	DESCAP(AM_4, AM)	162	FREQ(AM_2, AM)	4

FREQ(AM_3, AM)	4
FREQ(AM_4, AM)	4
FREQ(AM_5, AM)	4
FREQ(AM_6, AM)	4
FREQ(PM_1, PM)	2
FREQ(PM_2, PM)	2
FREQ(PM_3, PM)	2
FREQ(PM_4, PM)	2
FREQ(PM_5, PM)	2
FREQ(PM_6, PM)	2
FREQU(AM_1, AM)	0
FREQU(AM_2, AM)	0
FREQU(AM_3, AM)	0
FREQU(AM_4, AM)	1
FREQU(AM_5, AM)	1
FREQU(AM_6, AM)	0
FREQU(PM_1, PM)	0
FREQU(PM_2, PM)	0
FREQU(PM_3, PM)	0
FREQU(PM_4, PM)	0
FREQU(PM_5, PM)	0
FREQU(PM_6, PM)	0
FREQO(AM_1, AM)	5
FREQO(AM_2, AM)	5
FREQO(AM_3, AM)	9
FREQO(AM_4, AM)	0
FREQO(AM_5, AM)	0
FREQO(AM_6, AM)	1
FREQO(PM_1, PM)	7
FREQO(PM_2, PM)	7
FREQO(PM_3, PM)	11
FREQO(PM_4, PM)	1
FREQO(PM_5, PM)	1
FREQO(PM_6, PM)	3
TOTTRIPS(AM_1, AM)	9
TOTTRIPS(AM_2, AM)	9
TOTTRIPS(AM_3, AM)	13
TOTTRIPS(AM_4, AM)	3
TOTTRIPS(AM_5, AM)	3
TOTTRIPS(AM_6, AM)	5
TOTTRIPS(PM_1, PM)	9
TOTTRIPS(PM_2, PM)	9
TOTTRIPS(PM_3, PM)	13
TOTTRIPS(PM_4, PM)	3
TOTTRIPS(PM_5, PM)	3
TOTTRIPS(PM_6, PM)	5
TLB(AM_1, AM)	0
TLB(AM_2, AM)	0
TLB(AM_3, AM)	0
TLB(AM_4, AM)	0
TLB(AM_5, AM)	0
TLB(AM_6, AM)	0
TLB(PM_1, PM)	0
TLB(PM_2, PM)	0
TLB(PM_3, PM)	0
TLB(PM_4, PM)	0
TLB(PM_5, PM)	0
TLB(PM_6, PM)	0
TUB(AM_1, AM)	19
TUB(AM_2, AM)	19
TUB(AM_3, AM)	14
TUB(AM_4, AM)	14
TUB(AM_5, AM)	12
TUB(AM_6, AM)	5
TUB(PM_1, PM)	19
TUB(PM_2, PM)	19

TUB(PM_3, PM)	14	VUB(PM_1, PM)	7	FARE(AM_5, AM)	0.6
TUB(PM_4, PM)	14	VUB(PM_2, PM)	6	FARE(AM_6, AM)	0.6
TUB(PM_5, PM)	12	VUB(PM_3, PM)	4	FARE(PM_1, PM)	0.6
TUB(PM_6, PM)	5	VUB(PM_4, PM)	4	FARE(PM_2, PM)	0.6
VLB(AM_1, AM)	0	VUB(PM_5, PM)	3	FARE(PM_3, PM)	0.6
VLB(AM_2, AM)	0	VUB(PM_6, PM)	1	FARE(PM_4, PM)	0.6
VLB(AM_3, AM)	0	PASSKM(AM_1, AM)	1.031	FARE(PM_5, PM)	0.6
VLB(AM_4, AM)	0	PASSKM(AM_2, AM)	0.796	FARE(PM_6, PM)	0.6
VLB(AM_5, AM)	0	PASSKM(AM_3, AM)	0.629	REVENUE(AM_1, AM)	1855.8
VLB(AM_6, AM)	0	PASSKM(AM_4, AM)	0.633	REVENUE(AM_2, AM)	1432.8
VLB(PM_1, PM)	0	PASSKM(AM_5, AM)	0.488	REVENUE(AM_3, AM)	1094.76
VLB(PM_2, PM)	0	PASSKM(AM_6, AM)	0.1	REVENUE(AM_4, AM)	1085.4
VLB(PM_3, PM)	0	PASSKM(PM_1, PM)	1.031	REVENUE(AM_5, AM)	878.4
VLB(PM_4, PM)	0	PASSKM(PM_2, PM)	0.796	REVENUE(AM_6, AM)	180
VLB(PM_5, PM)	0	PASSKM(PM_3, PM)	0.629	REVENUE(PM_1, PM)	1855.8
VLB(PM_6, PM)	0	PASSKM(PM_4, PM)	0.633	REVENUE(PM_2, PM)	1432.8
VUB(AM_1, AM)	7	PASSKM(PM_5, PM)	0.488	REVENUE(PM_3, PM)	1094.76
VUB(AM_2, AM)	6	PASSKM(PM_6, PM)	0.1	REVENUE(PM_4, PM)	1085.4
VUB(AM_3, AM)	4	FARE(AM_1, AM)	0.6	REVENUE(PM_5, PM)	878.4
VUB(AM_4, AM)	4	FARE(AM_2, AM)	0.6	REVENUE(PM_6, PM)	180
VUB(AM_5, AM)	3	FARE(AM_3, AM)	0.6	ROUTECOST(AM_1, AM)	1308.206
VUB(AM_6, AM)	1	FARE(AM_4, AM)	0.6	ROUTECOST(AM_2, AM)	1235.198

ROUTECOST(AM_3, AM)	906.8672	CYCTM(AM_1, AM)	19	TYPES(PM_5, PM)	2
ROUTECOST(AM_4, AM)	721.4728	CYCTM(AM_2, AM)	16	TYPES(PM_6, PM)	2
ROUTECOST(AM_5, AM)	671.4088	CYCTM(AM_3, AM)	13.1	TYPESO(AM_1, AM)	1
ROUTECOST(AM_6, AM)	274.2464	CYCTM(AM_4, AM)	15.1	TYPESO(AM_2, AM)	1
ROUTECOST(PM_1, PM)	1308.206	CYCTM(AM_5, AM)	12.6	TYPESO(AM_3, AM)	0
ROUTECOST(PM_2, PM)	1235.198	CYCTM(AM_6, AM)	8	TYPESO(AM_4, AM)	0
ROUTECOST(PM_3, PM)	906.8672	CYCTM(PM_1, PM)	19	TYPESO(AM_5, AM)	0
ROUTECOST(PM_4, PM)	721.4728	CYCTM(PM_2, PM)	16	TYPESO(AM_6, AM)	0
ROUTECOST(PM_5, PM)	671.4088	CYCTM(PM_3, PM)	13.1	TYPESO(PM_1, PM)	0
ROUTECOST(PM_6, PM)	274.2464	CYCTM(PM_4, PM)	15.1	TYPESO(PM_2, PM)	0
LENGTH(AM_1, AM)	10	CYCTM(PM_5, PM)	12.6	TYPESO(PM_3, PM)	0
LENGTH(AM_2, AM)	8	CYCTM(PM_6, PM)	8	TYPESO(PM_4, PM)	0
LENGTH(AM_3, AM)	8	TYPES(AM_1, AM)	1	TYPESO(PM_5, PM)	0
LENGTH(AM_4, AM)	10	TYPES(AM_2, AM)	1	TYPESO(PM_6, PM)	0
LENGTH(AM_5, AM)	8	TYPES(AM_3, AM)	1	TYPESU(AM_1, AM)	0
LENGTH(AM_6, AM)	4	TYPES(AM_4, AM)	1	TYPESU(AM_2, AM)	0
LENGTH(PM_1, PM)	10	TYPES(AM_5, AM)	1	TYPESU(AM_3, AM)	0
LENGTH(PM_2, PM)	8	TYPES(AM_6, AM)	1	TYPESU(AM_4, AM)	0
LENGTH(PM_3, PM)	8	TYPES(PM_1, PM)	2	TYPESU(AM_5, AM)	0
LENGTH(PM_4, PM)	10	TYPES(PM_2, PM)	2	TYPESU(AM_6, AM)	0
LENGTH(PM_5, PM)	8	TYPES(PM_3, PM)	2	TYPESU(PM_1, PM)	0
LENGTH(PM_6, PM)	4	TYPES(PM_4, PM)	2	TYPESU(PM_2, PM)	0

TYPESU(PM_3, PM)	1
TYPESU(PM_4, PM)	1
TYPESU(PM_5, PM)	1
TYPESU(PM_6, PM)	1
NV(AM_1, AM)	3
NV(AM_2, AM)	3
NV(AM_3, AM)	3
NV(AM_4, AM)	1
NV(AM_5, AM)	1
NV(AM_6, AM)	1
NV(PM_1, PM)	3
NV(PM_2, PM)	3
NV(PM_3, PM)	3
NV(PM_4, PM)	1
NV(PM_5, PM)	1
NV(PM_6, PM)	1
MAXLEN(AM_1, AM)	22
MAXLEN(AM_2, AM)	22
MAXLEN(AM_3, AM)	22
MAXLEN(AM_4, AM)	22
MAXLEN(AM_5, AM)	22
MAXLEN(AM_6, AM)	22
MAXLEN(PM_1, PM)	22
MAXLEN(PM_2, PM)	22
MAXLEN(PM_3, PM)	22
MAXLEN(PM_4, PM)	22
MAXLEN(PM_5, PM)	22
MAXLEN(PM_6, PM)	22
MAXHEIGHT(AM_1, AM)	6
MAXHEIGHT(AM_2, AM)	6
MAXHEIGHT(AM_3, AM)	3
MAXHEIGHT(AM_4, AM)	6
MAXHEIGHT(AM_5, AM)	6
MAXHEIGHT(AM_6, AM)	6
MAXHEIGHT(PM_1, PM)	6
MAXHEIGHT(PM_2, PM)	6
MAXHEIGHT(PM_3, PM)	3
MAXHEIGHT(PM_4, PM)	6
MAXHEIGHT(PM_5, PM)	6
MAXHEIGHT(PM_6, PM)	6
STOCK(TAXI)	8
STOCK(SDBUS)	4
LF(TAXI)	0.9
LF(SDBUS)	0.9
CAPACITY(TAXI)	14
CAPACITY(SDBUS)	60
HRCOST(TAXI)	59.0016
HRCOST(SDBUS)	117.7882
KMCOST(TAXI)	0.478
KMCOST(SDBUS)	2.086
VEHLEN(TAXI)	5
VEHLEN(SDBUS)	9
VEHHEIGHT(TAXI)	2.4
VEHHEIGHT(SDBUS)	3.2
TVEHHRS(TAXI)	64
TVEHHRS(SDBUS)	32
TVEHDIST(TAXI)	464
TVEHDIST(SDBUS)	216
STOCKU(AM, TAXI)	0
STOCKU(AM, SDBUS)	0
STOCKU(PM, TAXI)	0
STOCKU(PM, SDBUS)	0
STOCKO(AM, TAXI)	0
STOCKO(AM, SDBUS)	0
STOCKO(PM, TAXI)	0
STOCKO(PM, SDBUS)	0

NVEHS(AM, TAXI)	8
NVEHS(AM, SDBUS)	4
NVEHS(PM, TAXI)	8
NVEHS(PM, SDBUS)	4
VDIFFO(AM, TAXI)	0
VDIFFO(AM, SDBUS)	0
VDIFFO(PM, TAXI)	0
VDIFFO(PM, SDBUS)	0
VDIFFU(AM, TAXI)	0
VDIFFU(AM, SDBUS)	0
VDIFFU(PM, TAXI)	0
VDIFFU(PM, SDBUS)	0
TRIPS(AM_1, AM, TAXI)	6
TRIPS(AM_1, AM, SDBUS)	3
TRIPS(AM_2, AM, TAXI)	6
TRIPS(AM_2, AM, SDBUS)	3
TRIPS(AM_3, AM, TAXI)	13
TRIPS(AM_3, AM, SDBUS)	0
TRIPS(AM_4, AM, TAXI)	0
TRIPS(AM_4, AM, SDBUS)	3
TRIPS(AM_5, AM, TAXI)	0
TRIPS(AM_5, AM, SDBUS)	3
TRIPS(AM_6, AM, TAXI)	5
TRIPS(AM_6, AM, SDBUS)	0
TRIPS(PM_1, PM, TAXI)	6
TRIPS(PM_1, PM, SDBUS)	3
TRIPS(PM_2, PM, TAXI)	6
TRIPS(PM_2, PM, SDBUS)	3
TRIPS(PM_3, PM, TAXI)	13
TRIPS(PM_3, PM, SDBUS)	0
TRIPS(PM_4, PM, TAXI)	0
TRIPS(PM_4, PM, SDBUS)	3
TRIPS(PM_5, PM, TAXI)	0
TRIPS(PM_5, PM, SDBUS)	3
TRIPS(PM_6, PM, TAXI)	5
TRIPS(PM_6, PM, SDBUS)	0
VEHS(AM_1, AM, TAXI)	2
VEHS(AM_1, AM, SDBUS)	1
VEHS(AM_2, AM, TAXI)	2
VEHS(AM_2, AM, SDBUS)	1
VEHS(AM_3, AM, TAXI)	3
VEHS(AM_3, AM, SDBUS)	0
VEHS(AM_4, AM, TAXI)	0
VEHS(AM_4, AM, SDBUS)	1
VEHS(AM_5, AM, TAXI)	0
VEHS(AM_5, AM, SDBUS)	1
VEHS(AM_6, AM, TAXI)	1
VEHS(AM_6, AM, SDBUS)	0
VEHS(PM_1, PM, TAXI)	2
VEHS(PM_1, PM, SDBUS)	1
VEHS(PM_2, PM, TAXI)	2
VEHS(PM_2, PM, SDBUS)	1
VEHS(PM_3, PM, TAXI)	3
VEHS(PM_3, PM, SDBUS)	0
VEHS(PM_4, PM, TAXI)	0
VEHS(PM_4, PM, SDBUS)	1
VEHS(PM_5, PM, TAXI)	0
VEHS(PM_5, PM, SDBUS)	1
VEHS(PM_6, PM, TAXI)	1
VEHS(PM_6, PM, SDBUS)	0
X(AM_1, AM, TAXI)	1
X(AM_1, AM, SDBUS)	1
X(AM_2, AM, TAXI)	1
X(AM_2, AM, SDBUS)	1
X(AM_3, AM, TAXI)	1
X(AM_3, AM, SDBUS)	0

X(AM_4, AM, TAXI)	0
X(AM_4, AM, SDBUS)	1
X(AM_5, AM, TAXI)	0
X(AM_5, AM, SDBUS)	1
X(AM_6, AM, TAXI)	1
X(AM_6, AM, SDBUS)	0
X(PM_1, PM, TAXI)	1
X(PM_1, PM, SDBUS)	1
X(PM_2, PM, TAXI)	1
X(PM_2, PM, SDBUS)	1
X(PM_3, PM, TAXI)	1
X(PM_3, PM, SDBUS)	0
X(PM_4, PM, TAXI)	0
X(PM_4, PM, SDBUS)	1
X(PM_5, PM, TAXI)	0
X(PM_5, PM, SDBUS)	1
X(PM_6, PM, TAXI)	1
X(PM_6, PM, SDBUS)	0

APPENDIX J.

RESULTS OF ROUTE EXTRACTION PROGRAM APPLIED TO WINNIPEG MODEL

The following pages present the basic output from the route extraction program applied to the output from the Emme/2 assignment process. The routes up to and including Route 63 are those produced by the regular part of the route extraction program. Almost all subsequently developed routes are either too short or have too little capacity to justify a service in terms of the original specification.

There is one significant exception to this, route number 85, which meets all the criteria. That it was not selected within the main group is believed to be the result of a weakness in the extraction process code, which it should be noted, is intended to demonstrate the concept only. Route number 107 could also be considered suitable for operation although possibly a borderline case.

In preparation for the resource allocation process, a filter can be applied to select any that meet more or less stringent criteria for inclusion in the resource allocation process. This is particularly useful if the development of routes for outstanding trips not meeting the extraction criteria has been employed.

Routes

Route	Exp	Mod	Capacity	Length	Pass.km	Utilisation	Time	Node_Sequence
1	✓	bq	93	10.76	520	0.52	20.70	181 180 179 178 177 176 175 174 173 172 171 170 169 168 167 166 165 1055 1059 1051 1050 1047 1046 1045 1044 1043 1042 1025 1021 1005 981 1005 1021 1025 1042 1043 1044 1045 1046 1047 1050 1051 1059 1055 165 166 167 168 169 170 171 172 173 174 175 176 177 178 179 180 181
2	✓	bq	209	9.98	1043	0.50	18.60	181 180 179 178 177 176 175 174 173 172 171 170 169 168 167 166 165 1055 1059 1051 1050 1047 1046 1045 998 988 998 1045 1046 1047 1050 1051 1059 1055 165 166 167 168 169 170 171 172 173 174 175 176 177 178 179 180 181
3	✓	bq	157	12.78	1000	0.50	25.40	616 615 614 613 612 611 610 609 608 607 606 605 604 603 602 601 600 599 598 887 899 898 901 917 931 937 948 966 981 1005 981 966 948 937 931 917 901 898 899 887 598 599 600 601 602 603 604 605 606 607 608 609 610 611 612 613 614 615 616
4	✓	bq	338	11.88	2312	0.58	25.10	889 893 892 891 890 418 419 422 423 436 437 438 440 441 442 443 444 445 451 452 454 458 454 452 451 445 444 443 442 441 440 438 437 436 423 422 419 418 890 891 892 893 889
5	✓	bq	211	10.48	974	0.44	19.90	181 180 179 178 177 176 175 174 173 172 171 170 169 168 167 166 165 1055 1059 1051 1050 1047 1046 1045 1044 1043 1042 1025 1021 1025 1042 1043 1044 1045 1046 1047 1050 1051 1059 1055 165 166 167 168 169 170 171 172 173 174 175 176 177 178 179 180 181
6	✓	bq	139	10.30	588	0.41	21.40	359 360 361 342 338 337 336 332 331 330 328 327 308 305 304 412 411 410 1034 1035 1036 1037 1038 1039 1040 1039 1038 1037 1036 1035 1034 410 411 412 304 305 308 327 328 330 331 332 336 337 338 342 361 360 359
7	✓	bq	210	14.08	1280	0.43	30.00	640 648 649 651 653 656 658 659 667 669 608 607 606 605 604 603 602 601 600 599 598 887 899 898 901 917 931 937 948 966 981 966 948 937 931 917 901 898 899 887 598 599 600 601 602 603 604 605 606 607 608 669 667 659 658 656 653 651 649 648 640
8	✓	bq	169	20.60	1433	0.41	34.60	657 612 611 610 609 608 516 517 518 519 527 533 534 535 540 539 494 1067 493 492 486 485 484 483 479 480 457 458 457 480 479 483 484 485 486 492 493 1067 494 539 540 535 534 533 527 519 518 517 516 608 609 610 611 612 657
9	✓	bq	97	13.12	635	0.50	26.90	260 261 279 252 248 247 246 245 244 241 219 221 202 168 167 166 165 1055 1059 1051 1050 1047 1046 1047 1050 1051 1059 1055 165 166 167 168 202 221 219 241 244 245 246 247 248 252 279 261 260
10	✓	bq	70	9.94	348	0.50	19.10	260 261 279 278 283 284 285 287 289 320 319 318 317 316 317 318 319 320 289 287 285 284 283 278 279 261 260

Route	Exp	Mod	Capacity	Length	Pass.km	Utilisation	Time	Node_Sequence
11		bq	215	26.66	3933	0.69	76.10	628 622 621 620 619 618 617 616 615 614 613 612 611 610 609 608 516 517 518 519 527 533 532 531 530 529 524 523 510 504 503 502 423 422 419 418 890 891 892 893 894 895 900 901 917 931 937 948 966 981 1005 1021 1025 1042 1043 1044 1045 1046 1047 1050 1051 1052 1053 1058 1053 1052 1051 1050 1047 1046 1045 1044 1043 1042 1025 1021 1005 981 966 948 937 931 917 901 900 895 894 893 892 891 890 418 419 422 423 502 503 504 510 523 524 529 530 531 532 533 527 519 518 517 516 608 609 610 611 612 613 614 615 616 617 618 619 620
12		bq	2060	33.78	13040	0.19	80.80	893 894 895 900 901 917 931 937 948 966 981 1005 1021 1025 1042 1043 1044 1045 1046 1047 1050 1051 1059 1055 165 166 167 168 202 221 219 241 244 245 246 247 288 289 320 321 322 381 387 390 401 367 365 364 363 336 335 334 429 428 427 426 425 424 423 422 419 418 890 891 892 893 892 891 890 418 419 422 423 424 425 426 427 428 429 334 335 336 363 364 365 367 401 390 387 381 322 321 320 289 288 247 246 245 244 241 219 221 202 168 167 166 165 1055 1059 1051 1050 1047 1046 1045 1044 1043 1042 1025 1021 1005 981 966 948 937 931 917 901 900 895 894 893
13		bq	357	11.36	2157	0.53	29.10	387 388 378 363 362 331 330 328 329 326 308 305 304 412 411 410 1034 1035 1036 1037 1038 1039 1040 1041 1042 1060 1042 1041 1040 1039 1038 1037 1036 1035 1034 410 411 412 304 305 308 326 329 328 330 331 362 363 378 388 387
14		bq	779	8.32	2435	0.38	16.10	845 846 847 849 850 829 826 813 811 784 781 782 783 1054 1053 1052 1051 1052 1053 1054 783 782 781 784 811 813 826 829 850 849 847 846 845
15		bq	1044	8.06	2872	0.34	17.40	182 181 180 179 178 177 176 175 174 173 172 171 170 169 168 169 170 171 172 173 174 175 176 177 178 179 180 181 182
16		bq	954	16.40	8028	0.51	49.20	619 618 617 616 615 614 613 612 611 610 609 608 607 606 605 604 603 602 601 600 599 598 887 899 898 901 902 905 906 908 909 910 911 912 958 959 960 988 998 1045 998 988 960 959 958 912 911 910 909 908 906 905 902 901 898 899 887 598 599 600 601 602 603 604 605 606 607 608 609 610 611 612 613 614 615 616 617 618 619
17		bq	935	9.44	3127	0.35	25.90	338 337 336 332 331 330 328 329 326 308 305 304 412 411 410 1034 1035 1036 1037 1038 1039 1040 1041 1042 1041 1040 1039 1038 1037 1036 1035 1034 410 411 412 304 305 308 326 329 328 330 331 332 336 337 338
18		bq	206	7.60	1105	0.71	19.10	826 825 824 823 817 808 788 770 771 772 741 742 735 734 733 912 958 912 733 734 735 742 741 772 771 770 788 808 817 823 824 825 826
19		bq	159	14.78	1581	0.67	39.00	171 170 169 812 811 784 781 782 780 777 778 738 913 912 733 734 735 730 699 700 701 702 681 703 704 705 706 707 710 709 710 707 706 705 704 703 681 702 701 700 699 730 735 734 733 912 913 738 778 777 780 782 781 784 811 812 169 170 171
20		bq	217	14.76	2611	0.82	34.10	338 339 347 453 454 452 451 445 444 443 442 441 440 438 437 436 423 415 414 973 414 415 423 436 437 438 440 441 442 443 444 445 451 452 454 453 347 339 338
21		bq	407	15.22	3793	0.61	36.20	512 513 514 515 517 516 608 607 606 605 604 679 680 681 702 701 700 699 730 735 736 729 728 727 726 725 724 745 724 725 726 727 728 729 736 735 730 699 700 701 702 681 680 679 604 605 606 607 608 516 517 515 514 513 512

Route	Exp	Mod	Capacity	Length	Pass.km	Utilisation	Time	Node_Sequence
22		bq	609	8.26	2173	0.43	21.40	825 826 813 811 784 781 782 780 777 778 738 739 740 741 742 735 734 733 912 733 734 735 742 741 740 739 738 778 777 780 782 781 784 811 813 826 825
23		bq	322	9.68	1443	0.46	18.50	370 369 368 367 360 343 347 453 454 458 454 453 347 343 360 367 368 369 370
24		bq	468	5.46	1090	0.43	16.30	525 524 523 510 504 503 502 423 415 423 502 503 504 510 523 524 525
25		bq	133	10.52	1323	0.95	18.00	531 530 529 496 495 494 1067 493 492 486 485 484 483 479 480 457 480 479 483 484 485 486 492 493 1067 494 495 496 529 530 531
26		bq	159	7.12	808	0.71	11.80	174 195 215 216 231 232 233 239 245 239 233 232 231 216 215 195 174
27		bq	154	5.54	610	0.71	6.50	240 247 248 252 279 252 248 247 240
28		bq	136	9.28	424	0.34	10.80	570 573 556 555 554 575 576 581 582 533 582 581 576 575 554 555 556 573 570
29		bq	303	3.38	640	0.63	8.90	592 591 889 893 923 925 941 944 970 975 1011 1015 1032 1031 1036 1037 1038 1037 1036 1031 1032 1015 1011 975 970 944 941 925 923 893 889 591 592
30		bq	348	2.04	417	0.59	5.10	592 591 889 893 894 895 900 895 894 893 889 591 592
31		bq	62	6.74	308	0.74	18.90	451 445 444 443 442 441 440 438 437 436 423 502 503 502 423 436 437 438 440 441 442 443 444 445 451
32		bq	173	3.92	523	0.77	12.50	600 692 691 689 698 697 885 907 906 905 902 901 902 905 906 907 885 697 698 689 691 692
33		bq	507	6.16	1076	0.34	14.20	489 490 491 442 441 440 438 437 436 423 436 437 438 440 441 442 491 490 489
34		bq	355	2.88	782	0.77	8.90	729 730 699 689 698 697 885 907 906 907 885 697 698 689 699 730 729
35		bq	74	5.92	256	0.58	16.00	454 458 457 456 455 454 455 456 457 458 454
36		bq	367	2.96	498	0.46	10.40	172 171 170 169 812 811 812 169 170 171 172
37		bq	358	3.98	397	0.28	10.90	769 770 773 775 776 777 778 738 913 912 913 738 778 777 776 775 773 770 769
38		bq	358	3.30	532	0.45	6.90	604 679 680 681 703 704 705 704 703 681 680 679 604
39		bq	315	6.02	676	0.36	13.80	845 836 822 823 817 808 788 770 771 772 741 772 771 770 788 808 817 823 822 836 845
40		bq	308	4.64	410	0.29	14.20	199 200 220 221 222 296 295 294 297 298 299 1064 1063 1064 299 298 297 294 295 296 222 221 220 200 199
41		bq	85	5.40	283	0.62	16.50	451 452 454 458 461 458 454 452 451
42		bq	83	9.18	234	0.31	15.30	185 184 872 873 874 875 876 878 853 851 850 851 853 878 876 875 874 873 872 184 185
43		bq	235	3.02	278	0.39	4.40	232 237 241 237 232
44		bq	75	2.82	112	0.53	6.40	695 691 689 699 700 701 700 699 689 691 695

Route	Exp	Mod	Capacity	Length	Pass.km	Utilisation	Time	Node_Sequence
45		bq	132	8.04	485	0.46	20.50	472 471 469 462 457 458 454 458 457 462 469 471 472
46		bq	213	3.24	437	0.63	8.50	736 743 768 767 766 765 790 791 790 765 766 767 768 743 736
47		bq	32	11.78	281	0.74	20.80	528 529 496 495 494 1067 493 492 486 485 484 483 479 480 457 462 469 462 457 480 479 483 484 485 486 492 493 1067 494 495 496 529 528
48		bq	168	3.84	332	0.52	10.10	506 512 507 508 509 504 501 499 439 440 439 499 501 504 509 508 507 512 506
49		bq	159	7.10	393	0.35	9.30	654 655 656 658 659 667 609 608 669 668 665 668 669 608 609 667 659 658 656 655 654
50		bq	64	4.76	260	0.85	7.60	347 339 335 339 347
51		bq	61	3.02	129	0.70	6.20	801 795 794 763 748 747 746 745 746 747 748 763 794 795 801
52		bq	137	2.54	206	0.59	7.60	326 311 312 313 314 297 314 313 312 311 326
53		bq	27	5.74	141	0.91	10.30	528 529 496 495 494 1067 493 492 486 485 486 492 493 1067 494 495 496 529 528
54		bq	81	5.62	131	0.29	10.70	262 275 279 278 283 282 283 278 279 275 262
55		bq	62	8.92	212	0.38	14.90	528 529 496 495 494 1067 493 492 543 542 543 492 493 1067 494 495 496 529 528
56		bq	106	12.04	360	0.28	17.70	471 477 478 479 483 484 485 486 492 493 492 486 485 484 483 479 478 477 471
57		bq	91	2.42	118	0.53	4.30	494 495 496 529 524 529 496 495 494
58		bq	77	2.20	46	0.27	6.20	443 442 450 447 449 447 450 442 443
59		bq	76	2.06	114	0.73	4.30	794 763 748 747 746 745 746 747 748 763 794
60		bq	74	5.34	182	0.46	9.10	558 559 561 560 631 629 628 629 631 560 561 559 558
61		bq	59	4.30	105	0.41	12.10	376 325 409 317 293 294 293 317 409 325 376
62		bq	58	4.58	105	0.39	10.90	262 275 279 261 260 259 260 261 279 275 262
63		bq	237	1.60	335	0.88	5.50	599 597 596 888 889 893 923 893 889 888 596 597 599

End of acceptable routes.

Route	Exp	Mod	Capacity	Length	Pass.km	Utilisation	Time	Node_Sequence
64		bq	174	0.96	88	0.53	3.80	411 410 1034 1035 1036 1031 1032 1031 1036 1035 1034 410 411
65		bq	304	0.56	99	0.58	1.80	739 733 739
66		bq	132	1.40	102	0.55	3.00	592 591 889 893 889 591 592
67		bq	195	0.74	72	0.50	1.50	851 850 851
68		bq	152	0.76	58	0.50	3.10	512 507 506 507 512
69		bq	165	1.20	160	0.81	4.00	738 737 991 994 1052 994 991 737 738
70		bq	177	0.98	87	0.50	5.30	461 458 461
71		bq	147	0.72	57	0.54	2.00	782 783 1054 1053 1054 783 782
72		bq	113	1.02	58	0.50	3.20	695 691 689 691 695
73		bq	159	0.42	33	0.50	1.80	901 902 905 902 901
74		bq	155	0.56	43	0.50	2.10	657 612 657
75		bq	88	0.18	9	0.54	1.10	1062 1061 1060 1061 1062
76		bq	152	0.76	62	0.54	3.10	411 410 1034 1035 1036 1035 1034 410 411
77		bq	149	0.44	37	0.56	1.70	848 847 848
78		bq	140	0.72	75	0.75	2.20	301 299 301
79		bq	139	0.06	4	0.50	0.30	1020 1019 1020
80		bq	122	0.56	34	0.50	1.90	502 423 502
81		bq	109	0.78	50	0.58	2.60	729 730 731 730 729
82		bq	107	0.06	3	0.50	0.20	1004 1003 1004
83		bq	105	0.96	50	0.50	2.00	362 331 362
84		bq	101	0.56	28	0.50	1.70	982 965 949 936 932 936 949 965 982
85		**bq**	**77**	**2.24**	**98**	**0.57**	**5.20**	**592 591 889 888 596 597 599 597 596 888 889 591 592**
86		bq	93	1.02	57	0.60	2.70	323 322 323
87		bq	85	1.90	81	0.50	6.00	454 458 454
88		bq	84	1.60	67	0.50	3.00	339 335 339
89		bq	23	1.68	19	0.50	3.20	533 532 531 532 533

Route	Exp	Mod	Capacity	Length	Pass.km	Utilisation	Time	Node_Sequence
90		bq	77	1.62	78	0.63	2.40	823 824 825 824 823
91		bq	66	0.12	4	0.50	0.90	1061 1060 1061
92		bq	43	1.52	33	0.50	3.50	469 462 457 462 469
93		bq	60	0.96	29	0.50	1.90	532 531 532
94		bq	59	0.34	10	0.50	1.70	1051 1050 1047 1046 1047 1050 1051
95		bq	51	0.52	22	0.82	1.50	730 735 730
96		bq	47	0.98	23	0.50	2.80	692 691 689 691 692
97		bq	41	0.22	5	0.50	0.70	512 507 512
98		bq	8	3.24	20	0.77	8.00	316 317 318 319 320 319 318 317 316
99		bq	8	2.46	10	0.50	8.00	533 527 519 518 517 518 519 527 533
100		bq	31	0.80	12	0.50	2.70	316 317 316
101		bq	29	1.10	16	0.50	5.10	519 518 517 518 519
102		bq	28	0.42	6	0.50	1.20	443 444 443
103		bq	27	0.62	12	0.74	2.20	738 737 738
104		bq	23	0.68	8	0.50	2.00	692 600 692
105		bq	22	1.64	31	0.86	2.40	856 846 856
106		bq	22	0.42	5	0.53	1.20	783 1054 1053 1054 783
107		**bq**	**20**	**4.94**	**49**	**0.50**	**8.20**	**351 350 349 348 344 343 342 343 344 348 349 350 351**
108		bq	19	1.12	11	0.52	1.60	592 591 889 591 592
109		bq	18	0.62	6	0.50	1.20	462 457 462
110		bq	14	0.48	3	0.50	1.10	533 534 533
111		bq	7	1.72	12	1.00	3.30	318 319 320 319 318
112		bq	5	0.74	3	0.80	1.10	823 824 823
113		bq	4	0.48	1	0.50	1.30	692 691 692
114		bq	2	1.12	1	0.50	3.30	435 441 435
Totals:			21105	569.38	76420	0.54		

Group	TriggerVal	MinVol	MinLen	MinUtil
Road	50	50	8	0.25
Road	1000	200	8	0
Road	98	0	4	0

APPENDIX K.

USING DIJKSTRA'S ALGORITHM FOR ROUTE EXTRACTION

As mentioned in the body of the discussion, a problem with the route extraction method described, is that it depends on the sort order of the network links in the database. This leads to a potentially arbitrary result when there is a choice of link in developing a route. For example, when the highest demand occurs on two or more non-adjacent links or when one link leads into two links of equal demand. This can be overcome by using an adaptation of Dijkstra's shortest path algorithm, as demonstrated in the accompanying spreadsheet "ShortestPath.xls." This has not been implemented fully due to the problems of efficient coding for a large network. These are far from insurmountable but are out of the scope of this dissertation. Very shortly, "link length" is determined as a function of link demand. The greater the demand, the "shorter" the link. In essence, the method proceeds as follows:

For all links of the mode group (road, rail, etc.) in the network, with any demand whatsoever:

1. Create a pointer array to renumber the nodes, connected to links carrying some demand, from 1 to N. This is used to output the results with the actual node numbers while using a sequential node numbering system for the processing. Determine N in the process of renumbering.
2. Create an N by N array to describe the "path length" from every node I to every node J.
3. Determine the maximum demand (MaxVol) on the network. (It does not matter how many times it occurs.)
4. Determine a "path length" for each link as:

   Path length = MaxVol – link demand

   Any link (I,J) with a zero demand is set as having a very high "path length" except when I=J when the path length is set to zero.
5. Dijkstra's shortest path algorithm is then applied to determine the "shortest path" from every I to every J. The modified process stores the details of the path; node sequence, length, travel time, link demand etc. This process determines all possible routes based on the demand on the links as if no other route exists.
6. The routes thus developed are tested to eliminate all paths fully contained within longer paths. The path 13, 14, 15 is thus eliminated because it is fully contained in the path 1,13,14,15,16,5.

7. Routes listed during an iteration but not including the maximum demand value on their path are kept for testing outstanding trips only.
8. The capacity of routes including a MaxVol link, is determined taking into account the length of route segments left with demand as a result of setting a particular capacity. (i.e. Is there a fully included route?) The vehicle separation process can also be included at this stage with the advantage that potential routes for all vehicle classes can be tested simultaneously. This deals with most of the "outstanding trip" problems described earlier.
9. The remaining paths are then tested against one or more of a variety of criteria. Examples are; Vehicle utilisation, average passengers per kilometre, total passenger kilometres according to the planner's primary objectives.
10. The best of these is chosen and saved. The path length array is recreated to reflect the remaining demand after the last declared route is accounted for.
11. The process is repeated until no potential routes remain.

An interesting observation arising from experimentation with this technique on the Transit example is that the measure of route efficiency, vehicle utilisation for example, used as the selection criterion has a strong impact on the results. In fact, the technique seems to produce an apparent reduction in system efficiency in terms of total utilisation and number of transfers required over that of the method described in the main text. Nevertheless, the author believes that this technique offers significant potential and needs further research.

APPENDIX L.

TEMPLATE GOAL-PROGRAM MODEL.

This model is included on the accompanying CD as "Resources.lg4."

MODEL:

Title BatchData;

!NOTES:
This model is constructed for operation in conjunction with Microsoft Office Access 97 on a Windows 95/98/NT platform.

The "Title" statement directs the lingo program to the ODBC source and is required. IF THE RouteExtractor DATABASE IS MOVED TO ANOTHER DRIVE OR DIRECTORY, THE ODBC REFERENCE WILL CHANGE AND MUST BE ALTERED USING THE ODBC MANAGER.

When the Lingo model is run from within the database, the Lingo Solution is not available. The results are only available from the database destination fields. In order to run the model and view the solution within Lingo, the model must be called by Lingo as a stand alone model.

It is possible to save the model in a "script" format that allows the Lingo solution process to be entirely hidden. Calling the solver from the database will invoke Lingo as a hidden module. This makes testing and editing difficult and has not been implemented. The order of display of the results in the Lingo solution is controlled by and the same as that of the listing in the Sets section.

The position of the brackets in the equations containing the deviational variables is important. The summation set brackets must be closed before the deviational variables. If this is not done the deviation is multiplied by the number of primary set elements. For example, if there are three routes and routes are the primary set, then the deviational variables will be multiplied by 3. See the goal statements in the model for the correct structure.

The inclusion of bounds on variables can help to reduce the search time. The bounds must be numeric or fixed variables given values in the Data section.

CARE MUST BE TAKEN WHEN EVALUATING BOTH INPUT AND OUTPUT. SOME VALUES ARE BASED ON THE DESIGN HOUR WHILST OTHERS REFLECT THE FULL OPERATING PERIOD.

The model is designed to extract only road based routes and vehicle types from the database according to a code in the route and vehicle tables. It is possible to create a group based allocation by adding additional sets. This has not been considered justified at this stage. The model is thus "fixed" on road mode.

EndNotes;

```
!DEFINITIONS:

Most of the variables have names which describe them.  A few additional clarifications
are given here.

Length = round trip length.  The travel distance may not be the same for both directions.
?o = Weight of over-utilisation.
?u = Weight of under-utilisation.
ho = Ratio of peak hour to operating period passenger kilometers.

EndDefs;

!---------------------------------------------------------------------------------;

SETS:
!NOTE: If the Periods table includes periods for which routes are not defined, a
 warning will be issued by Lingo but the process will continue without error.;
         Periods / @ODBC(BatchData, Periods, Period)/:
                          Start_Time, TLength,
                          ho,
                          MinDem,
                          PFreq,
                          PCost;

EndSets

DATA:
Start_Time    = @ODBC(BatchData, Periods, Start_Time);        !Period Start time in 24 hr
time;

TLength       = @ODBC(BatchData, Periods, TLength);            !Length of the operating
period in hours;

ho            = @ODBC(BatchData, Periods, ho);         !The ratio operating period total
demand /design hour demand for the system;

PFreq         = @ODBC(BatchData, Periods, PeriodFrequency);!Number of occurences of this
operating period in the resource allocation period.  If resource allocation is per day, then a period
will occur only once usually.  For a week, a weekday period will normally occur five times.;

PCost         = @ODBC(BatchData, Periods, PCost);      !Hourly cost factor to account for
different operating period wages.;

!ho could be modified to reflect a route value which would be much more accurate
 but which would increase the number of variables by the number of routes.;

EndData
```

```
SETS:
        AllRoutes /@ODBC(BatchData, QRoutes, Line)/: Period;

EndSets

DATA:
        Period = @ODBC(BatchData, QRoutes, PeriodNo);                !The period name;
EndData

SETS:
        Routes(AllRoutes, Periods )|(Period(&1) #EQ# (&2)):
                        Demand, Demandu, Demando, DesCap,TotCap,
                        Freq, Frequ, Freqo, TotTrips, Tlb, Tub, Vlb, Vub,
                        PassKm, Fare, Revenue, RouteCost,
                        Length, CycTm,
                        Types, Typeso, Typesu,
                        Nv, MaxLen, MaxHeight;


        Modes /@ODBC(BatchData, QVehicles, Short Description)/:
                        Stock,
                        Lf, Capacity,
                        HrCost, KmCost,
                        VehLen, VehHeight,
                        TVehHrs, TVehDist;

        TempStock(Periods, Modes):
                        Stocku, Stocko, NVehs, VDiffo, VDiffu;

        Lines(Routes, Modes):
                        Trips, TVB, Vehs, VVB, X;

EndSets

!-------------------------------------------------------------------------------;

!MINIMISE THE SUM OF THE WEIGHTED GOAL DEVIATIONS;
!In the objective function as presented here, one trip not assigned is the equivalent of one
frequency not provided or one vehicle extra.  However, since the passenger not carried is lost
revenue and the vehicle trip not provided is a reduced cost, the decision becomes one of cost.
Because of the load factor component, there will generally be space for a few extra passengers
and so the system will tend to balance itself out.  An almost identical state of affairs exists for the
stock.

The model may have to be run a number of times to establish the multiplier for the  netcost
which should generally be measured in thousands or millions of Rand.;
```

```
[OBJECTIVE]
                Min = @Sum(Routes(R,P):   Du * Demandu(R,P)
                                       +  Do * Demando(R,P))
                  +   @Sum(Routes(R,P):   Fu * Frequ(R,P)
                                       +  Fo * MinDem(P) * Freqo(R,P) / Demand(R,P))
                  +   @Sum(Routes(R,P):   Tu * Typesu(R,P)
                                       +   (NoModes #GT# Types) * To * Typeso(R,P))
                  +   @Sum(TempStock(P,V):      Su * Stocku(P,V)
                                       +  (1 - EnfStock)* So * Stocko(P,V))
                                       +  (NoPeriods #GT# 1) * Dv * MaxDiff
                                       +  WCost * Netcost;

!(1 - EnfStock) If the stock limit is enforced, then Stocko cannot be non-zero;
!(NoModes #GT# Types) We are normally only interested in the problem of too many types.
Typeso is only relevant if there are more vehicle types available than are allowed on a route.;
!(NoPeriods #GT# 1) Maxdiff only has meaning when there is more than one period.;

!-----------------------------------------------------------------------------;

!MEET DEMAND;
!This is the highest demand hour in the operating period. The "Demand" value is the demand on
the maximum load section and cannot be used to determine the passenger-kilometres.;
@For(Routes(R,P):[MEETDEMAND]
        @Sum(Lines(R,P,V):  Trips(R,P,V) * Lf(V) * Capacity(V))
                                + Demandu(R,P) - Demando(R,P) = Demand(R,P));

!CONVERT TRIPS TO VEHICLES;
@For(Lines(R,P,V):[TRIPSTOVEHS]
        Trips(R,P,V)* CycTm(R,P)- 60 * Vehs(R,P,V) < 0);

!USE ONLY AVAILABLE VEHICLES;
!If no additional vehicles can be brought in, then EnfStock = 1 else = 0.;
@For(TempStock(P,V):[AVAILABLEVEHS]
        @Sum(Lines(R,P,V):   Vehs(R,P,V))
                                        + Stocku(P,V) - (1 - EnfStock) * Stocko(P,V) = Stock(V));

!NUMBER OF VEHICLES OF EACH TYPE OPERATING IN EACH PERIOD;
@For(TempStock(P,V):
        @Sum(Lines(R,P,V):   Vehs(R,P,V)) = NVehs(P,V));

!ESTABLISH THE DIFFERENCE BETWEEN THE NUMBER OF EACH TYPE OF
VEHICLE USED IN EACH PERIOD.;
@For(TempStock(P,V)|P #LT# NoPeriods #AND# NoPeriods #GT# 1:
        @Sum(TempStock(I,V)|I #EQ# P+1:
                (NVehs(P,V)- NVehs(I,V)) + VDiffu(P,V) - VDiffo(P,V)) = 0);

!This generates one constraint for each consecutive pair of periods if there is more than one
period. If there is only one period, the constraint falls away. The sum VDiffu + VDiffo is the
equivalent of the absolute value of the difference. We seek to minimise the maximum of this
value across all time periods to some degree.
```

It will be seen that there are VDiff terms for one period more than expected. This does not influence the results. The 100 factor is intended to limit the influence of the difference in the result. This only comes into effect if there is more than one period.;

```
@For(TempStock(P,V)|NoPeriods #GT# 1:
        100 * MaxDiff - (VDiffu(P,V) + VDiffo(P,V)) > 0);
```

```
!MEET MINIMUM POLICY FREQUENCY;
@For(Routes(R,P):[MINFREQ]
        @Sum(Lines(R,P,V):  Trips(R,P,V))
                                        + Frequ(R,P) - Freqo(R,P) = Freq(R,P));
```

!ROUTE AND TOTAL REVENUES.
The passenger-kilometres are given for the peak demand hour only. In order to determine the total for the operating period and thus the total revenue, we need the passenger-kilometres in the other hours in the period. If these are precisely known then they can be added directly to the database. If not, then an alternative is required. The ho(P) factor is used to allow for this. It represents the system wide ratio of the pass.km for the period to those or the design hour. This could be changed to a route based value for greater accuracy.

The revenue depends on the number of places provided. The number of paying passengers cannot exceed the total capacity. We do not know the precise relationship between the peak load section and the passenger kilometres so this is a proportionate estimate if the supply is less than the demand. 1000 multiplier because Passenger Km given in 1000's. Numerator of 2 to deal with two-way length.;

!Measured in thousands of Rand because the PassKm are provided in thousands and the fare in Rand. NOTE: DON'T FORGET THE HO FACTOR WHEN COMPARING WITH THE DATABASE.;

```
@For(Routes(R,P):
[INCOME]            Revenue(R,P) =  Fare(R,P)* ho(P) * (PassKm(R,P) * 1000
                                             - Length(R,P) * Demandu(R,P)/ 2));

[TOTALREVENUE]          TotRevenue = @Sum(Routes(R,P): PFreq(P) * Revenue(R,P));
```

!DETERMINE THE ROUTE AND TOTAL COSTS;
!Assumes that the vehicle is costed for the full period TLength(P), for any part of a period operated. The number of vehicles required is unaffected assuming whole hour periods only. RouteCost is measured in units of MCost Rand where MCost represents 1000's, Millions, etc.;

```
@For(Routes(R,P):[RCOST]
        @Sum(Lines(R,P,V):  TLength(P) * (Trips(R,P,V) * KmCost(V) * Length(R,P)
                               + Vehs(R,P,V) * PCost(P) * HrCost(V))) =  RouteCost(R,P));
```

!The first line covers the variable cost of the trips per hour Trips(PRV) for the entire operating period TLength(P).

The second line estimates the total fixed cost. It is assumed that when one or more of the vehicles run over the end of the operating period in order to complete the last cycle, that the vehicle also started later. This would allow some flexibility in staff schedules and is thus not accounted for separately.;

```
[TCOST]              TotalCost = @Sum(Routes(R,P):PFreq(P) * RouteCost(R,P));


!DETERMINE THE NET COST:  In units of MCost, e.g. 000's.;
[NETREV]             NetCost * MCost = (TotalCost - TotRevenue) ;


!LIMIT THE SUBSIDY TO WITHIN THE BUDGET AVAILABLE;
!This is not included as a bound because it may not be enforced.  The netcost is +ve if a  subsidy
is required and negative if a profit is being achieved.  Since MaxSub is a +ve  value, this will
always result in a limit on the subsidy but have no impact on any profir  that might be achieved.;
[LIMITSUBS]          EnfSubs * NetCost < MaxSub;

!MAXIMUM VEHICLE LENGTH ON ROUTE;
!Constraints are only generated when the vehicle length is greater than the maximum allowed;
@For(Lines(R,P,V)|VehLen(V) #GT# MaxLen(R,P):[VEHICLE_LENGTH]
        X(R,P,V) * VehLen(V) - MaxLen(R,P) < 0);

!MAXIMUM VEHICLE HEIGHT ON ROUTE;
!Constraints are only generated when the vehicle height is greater than the maximum allowed;
@For(Lines(R,P,V)|VehHeight(V) #GT# MaxHeight(R,P):[VEHICLE_HEIGHT]
        X(R,P,V) * VehHeight(V) - MaxHeight(R,P) < 0);

!-----------------------------------------------------------------------------;
!INPUT DATA CALCULATIONS ONLY;

!NUMBER OF ROUTES;
NoRoutes = @Size(Routes);

!TOTAL DESIGN PERIOD TIME;
TotTime = @Sum(Periods(P): TLength(P));

!MIN DEMAND OF ALL ROUTES;
!This will produce a warning message if periods are specified for which no routes are specified;
@For(Periods(P):
        @Min(Routes(R,P): Demand(R,P))= MinDem(P));

!FORCE TRIPS, VEHICLES AND X TO HAVE CORRECT VALUES.;
@For(Lines(R,P,V):[XTRIPS] Trips(R,P,V) - TVB(R,P,V) * X(R,P,V) < 0);      !Force X to 1;
@For(Lines(R,P,V):[XVEHS]  Vehs(R,P,V)  - VVB(R,P,V) * X(R,P,V) < 0);      !Force X to 1;
@For(Lines(R,P,V):[TRIPSX] X(R,P,V) - Trips(R,P,V) < 0);                   !Force X to 0;
@For(Lines(R,P,V):[VEHSX]  X(R,P,V) - Vehs(R,P,V)  < 0);                   !Force X to 0;

!NUMBER OF VEHICLE TYPES OPERATING ON ROUTE;
@For(Routes(R,P)|NoModes #GT# Types #OR# TU #GT# 0:[NUMTYPES]
        @Sum(Lines(R,P,V): X(R,P,V)) + Typesu(R,P) - Typeso(R,P) = Types(R,P));

!-----------------------------------------------------------------------------;
```

```
!BOUND AND TYPE CONSTRAINTS;
!These are included on the basis that bounds have no weight in the number of constraints and can
improve solution time. The upper bounds should not require changing.  The lower bounds are
mostly controlled by selecting the desired input statements.;

@For(Routes(R,P):[ROUTEBOUNDS]
        @BND(Tlb(R,P), TotTrips(R,P), Tub(R,P)); !Limit trips to within frequency bounds.  Tlb
is  set in the data section;
        @BND(0, Demandu(R,P), Demand(R,P));    !Undersupply   cannot   be   greater   than
demand.;
        @BND(0, Demando(R,P), MaxCap);         !Should be maximum vehicle capacity.  i.e.
One trip of the largest vehicle type.  MaxCap must be determined in database.;
        @BND(0, Frequ(R,P), Freq(R,P));        !Undersupply cannot be greater that policy.;
        @BND(0, Freqo(R,P), Tub(R,P)-Freq(R,P)));     !Overachievement   cannot   exceed
freq.  bound - policy frequency.;

@For(Lines(R,P,V):[LINEBOUNDS]
        @BND(0, Trips(R,P,V), TVB(R,P,V));     !No. vehicles trips cannot exceed maximum
of  number of trips of vehicle type required to  meet all demand or satisfy policy frequency.;

        @BND(0, Vehs(R,P,V),  VVB(R,P,V));     !No.  of  vehicles  of  type  will  not  exceed
Max of number required meet demand or satisfy  policy frequency.;

        @BND(0, Typesu(R,P), Types(R,P));      !Typesu cannot be greater than policy.;
        @BND(0,  Typeso(R,P),  NoModes-Types(R,P))); !Typeso  cannot  be  greater  than  no.
modes less policy number of types.  NoModes  must be determined in database.;

@For(TempStock(P,V):[TMPSTCKBNDS]
        @BND(0, Stocku(P,V), Stock(V))); !Unused vehicles must be <= stock.;

!________________________________________________________________________________

!USE THIS LINE IF IT IS CLEAR THAT THE DEMAND CAN BE MET.  These limits do not
cater for the policy frequency, only for the demand.;
!@For(Routes(R,P):
        @BND(VLB(R,P), NV(R,P), VUB(R,P)));          !The  total  number  of  vehicles  must
be in this range.;

!USE THIS LINE IF IT IS NOT CLEAR THAT THE DEMAND CAN BE MET.;
@For(Routes(R,P):
        @BND(0, NV(R,P), VUB(R,P)));          !The total number of vehicles must be in this
range.;

!________________________________________________________________________________

!THIS  SECTION  MUST  BE  MODIFIED  ACCORDING  TO  WHETHER  OR  NOT  THE
INTEGER SOLUTION IS TO BE DETERMINED;

!DECLARE INTEGER AND BINARY VARIABLES;
@For(Lines(R,P,V):[GIN_INT]
```

```
        @Gin(Trips(R,P,V));                    !BLOCK THIS LINE FOR THE LP
PROBLEM ONLY;
        @Gin(Vehs(R,P,V)));         !BLOCK THIS LINE FOR THE LP PROBLEM ONLY;


!X(R,P,V) is used for a number of purposes but can be eliminated providing certain constraints
and goals are not being imposed.;
@For(Lines(R,P,V):[BIN_INT]
        @BIN(X(R,P,V));             !BLOCK THIS LINE FOR THE LP PROBLEM ONLY;

!LIMIT THE VALUE OF X TO <=1 FOR THE NON-INTEGER SOLUTION CASE. Since the
MIP problem is solved by first solving the LP, this might help to bound the LP solution.;
        @Bnd(0, X(R,P,V), 1));

!______________________________________________________________________________

!FREE NetCost VARIABLE TO TAKE ON NEGATIVE VALUES;
@Free(NetCost);

!IF IT IS CERTAIN THAT THE DEMAND CAN BE MET ON ALL ROUTES, THEN BLOCK
THIS LINE AS THIS CAN  REDUCE THE SOLUTION TIME.;
!@For(Routes(R,P): @Free(Revenue(R,P))); !If a route is not served, the Revenue can take on
a negative value due to its conservative estimation.;

!-------------------------------------------------------------------------------;
!OUTPUT CALCULATIONS;

!DETERMINE SUPPLIED MAXIMUM CAPACITY;
@For(Routes(R,P):[MAXIMUMCAP]
        @Sum(Lines(R,P,V):  Trips(R,P,V) * Capacity(V)) = TotCap(R,P));

!DETERMINE SUPPLIED DESIGN CAPACITY;
@For(Routes(R,P):[DESIGNCAP]
        @Sum(Lines(R,P,V):  Trips(R,P,V) *  Lf(V)* Capacity(V)) = DesCap(R,P));

!NUMBER OF VEHICLES OPERATING ON EACH ROUTE;
@For(Routes(R,P):[NUMVEHS]
        @Sum(Lines(R,P,V): Vehs(R,P,V)) = NV(R,P));

!DETERMINE THE TOTAL NUMBER OF VEHICLE TRIPS PROVIDED;
@For(Routes(R,P):[PROVIDEDTRIPS]
        @Sum(Lines(R,P,V): Trips(R,P,V)) = TotTrips(R,P));

!ESTIMATE THE TOTAL PASSENGER KILOMETRES;
!This is an estimate of the passenger kilometres travelled for all the operating periods for the
resource allocation period.  For example, the AM peak will occur five  times in an allocation
period of one week.  The division by 1000 is applied to the   Demandu factor because the
PassKm are given in 1000's of passenger kilometres.;
[TOTALPASSKM]
        100 * TotPassKmXK = @Sum(Routes(R,P): PFreq(P) *
        (ho(P) * (PassKm(R,P)*100 - Length(R,P) * Demandu(R,P)/10)));
```

```
!DETERMINE TOTAL VEHICLE OPERATING HOURS FOR EACH VEHICLE TYPE;
@For(Modes(V):
        @Sum(Lines(R,P,V):Vehs(R,P,V)*TLength(P))=TVehHrs(V));

!DETERMINE TOTAL VEHICLE KILOMETRES FOR EACH VEHICLE TYPE;
@For(Modes(V):
        @Sum(Lines(R,P,V):Trips(R,P,V)*Length(R,P))=TVehDist(V));

!--------------------------------------------------------------------------------;

DATA:

MCost = 1000;
!Lingo input data;

!Objective rankings                                  DEFINITIONS - Weights and
switches;
Do          =@ODBC(BatchData, GPRanks, Do);          !Weight:Over supply of capacity;
Du          =@ODBC(BatchData, GPRanks, Du);          !Weight:Under supply of capacity;
Fo          =@ODBC(BatchData, GPRanks, Fo);          !Weight:Over policy frequency;
Fu          =@ODBC(BatchData, GPRanks, Fu);          !Weight:Under policy frequency;
So          =@ODBC(BatchData, GPRanks, So);          !Weight:Over utilisation of fleet;
Su          =@ODBC(BatchData, GPRanks, Su);          !Weight:under utilisation of fleet;
EnfStock    =@ODBC(BatchData, GPRanks, EnfStock);!Switch:Constrained fleet;
To          =@ODBC(BatchData, GPRanks,To);           !Weight:Excess vehicle types;
Tu          =@ODBC(BatchData, GPRanks,Tu);           !Weight:Too few vehicle types;
Wcost       =@ODBC(BatchData, GPRanks, Subs);        !Weight:Cost / Profit;
EnfSubs     =@ODBC(BatchData, GPRanks, EnfSubs);     !Switch:Constrained subsidy;
MaxSub      =@ODBC(BatchData, GPRanks, MaxSub);      !Maximum subsidy allowed;
DV          =@ODBC(BatchData, GPRanks, DV);          !Weight:Imbalance in number of
                                                             vehicles between periods.;


!System data                                         DEFINITIONS - for system;
NoModes     =@ODBC(BatchData, NoModes, NoModes);!Count of number of road modes.
Determined in DB because used asa bound value an thus cannot be determined within Lingo.;
MaxCap      =@ODBC(BatchData, VehData, MaxCap); !Maximum design capacity of
available modes. See note above.;
MinCap      =@ODBC(BatchData, VehData, MinCap); !Minimum design capacity of
available modes. See note above.;
NoPeriods   =@ODBC(BatchData, NoPeriods, NoPeriods); !Number of periods defined.;


!Route data                                                DEFINITIONS - for route;
Demand      =@ODBC(BatchData, QRoutes, Demand);            !Peak section demand;
Length      =@ODBC(BatchData, QRoutes, Length);            !Round trip length. May not
be the same for both directions;
Freq        =@ODBC(BatchData, QRoutes, Frequency);         !Policy frequency;

!-----------------------------------------------------------------------------------;
```

```
!USE THESE LINES IF IT IS CLEAR THAT THE DEMAND CAN BE MET.  These allow for
demand but  not policy frequency.;
Tlb          =@ODBC(BatchData, QRoutes, LBTrips);           !Determined   from   demand
and fleet;
Vlb          =@ODBC(BatchData, QRoutes, VLB);               !Calculated          minimum
possible number of vehicles;

!USE THESE LINES IF IT IS NOT CERTAIN THAT THE DEMAND CAN BE MET.;
!Tlb         =0;
!Vlb         =0;

!------------------------------------------------------------------------------------;
TVB          =@ODBC(BatchData, Lines, TVB);                 !Upper bound of vehicle type
trips on route;
VVB          =@ODBC(BatchData, Lines, VVB);                 !Upper bound of vehicle type
on  route;

Tub          =@ODBC(BatchData, QRoutes, UBTrips);           !Upper bound of vehicle trips
on  route;
Vub          =@ODBC(BatchData, QRoutes,VUB);                !Upper   bound   of   vehicles
required on route;

CycTm        =@ODBC(BatchData, QRoutes, MinCycleTime);      !Cycle time;
Fare         =@ODBC(BatchData, QRoutes, Fare);              !Fare per kilometre;
PassKm       =@ODBC(BatchData, QRoutes, mPassengerKm);      !Estimated           maximum
passenger kilometres in 1000's;
MaxLen       =@ODBC(BatchData, QRoutes, MaxLen);            !Maximum allowable vehicle
length;
MaxHeight    =@ODBC(BatchData, QRoutes, MaxHeight);         !Maximum allowable vehicle
height;
Types        =@ODBC(BatchData, QRoutes, Types);             !Target   number   of   vehicle
types;

!Vehicle data                                               DEFINITIONS - for vehicles;
Capacity     =@ODBC(BatchData, QVehicles, capt);            !Vehicle total capacity;
Stock        =@ODBC(BatchData, QVehicles, Fleet size);      !Number       of       vehicles
available;
Lf           =@ODBC(BatchData, QVehicles, LoadFactor);      !Load factor;
KmCost       =@ODBC(BatchData, QVehicles, cdc);             !Cost per kilometre;
HrCost       =@ODBC(BatchData, QVehicles, ctc);             !Cost per hour;
VehLen       =@ODBC(BatchData, QVehicles, VehLen);          !Length of vehicle;
VehHeight    =@ODBC(BatchData, QVehicles, VehHeight);       !Height of vehicle;
```

```
!Lingo Output data;

!Table : Lines;
!The (Routes, Period. Vehicles) of the table definition are the database field names associated
with the (Routes, Periods, Modes) of the Lines Set;
@ODBC(BatchData, Lines, Routes, Period, Vehicles, FleetSize, Trips) = Lines, Vehs, Trips;

!Table : QVehicles;
@ODBC(BatchData, QVehicles, TotalVehDistance) = TVehDist;  !Total vehicle distance;
@ODBC(BatchData, QVehicles, TotalVehHours) = TVehHrs;      !Total vehicle hours;

!Table : QRoutes                                      DEFINITIONS - output for route;
@ODBC(BatchData, QRoutes, TotalVehicles) = Nv;              !Number of vehicles used;
@ODBC(BatchData, QRoutes, TotalCost) = RouteCost;           !Estimated cost of operation;
@ODBC(BatchData, QRoutes, GrossRevenue) = Revenue;          !Estimated revenue;
@ODBC(BatchData, QRoutes, ProvidedCapacity) = TotCap;       !Total capacity provided;
@ODBC(BatchData, QRoutes, Practical Frequency) = TotTrips;  !Total number of vehicle
trips provided;

!Table : NetworkData                                 DEFS - output for NetworkData;
@ODBC(BatchData, NetworkData, NetCost) = NetCost;  !Netcost of service.  We must
convert this from the scaled currency format to conventional currency format in the database
otherwise a problem develops when the cost and revenue are nearly equal.;
@ODBC(BatchData, NetworkData,MCost) = MCost;                !Currency scale factor.;
@ODBC(BatchData, NetworkData, TotalCost) = TotalCost;       !Netcost of service;
@ODBC(BatchData, NetworkData, TotRevenue) = TotRevenue;     !Netcost of service;

ENDDATA

END
```

APPENDIX M.

AN OPERATOR ASSIGNMENT MODEL

This model is on the accompanying CD as "Tenders.lg4." The model is not associated with the database in any way although it could be readily adapted to link to the database. (The data for the example is contained within the model, which can be run using the Demo version of Lingo.) The link has not been provided here because the allocation process will depend on the form of the contracts and the model must thus be developed for each project separately. The objective here is to demonstrate the form of the model and to demonstrate that the same modelling tools used for the fleet assignment can also be used in other areas of the process.

Model:

```
! This particular version of the model assumes that an operator provides a route based and not a
vehicle based tender - i.e. one cannot accept part of a route tender. Hence the failure to meet all
the demand with the available tenders;

Title: Tenders;
Sets:
Operators / a, b, c /:TCap;      !Total capacity of operator;
Routes / _1, _2, _3 /:Demand, NumOps, Supu, Supo, Numu, Numo;
                  !Demand      = required peak section capacity on route.
                  NumOps       = number of operators that may be accepted to serve route.
                  Supu         = underachievement of required capacity.
                  Supo         = overachievment of required capacity.
                  Numu         = underachievement of number of operators allowed.
                  Numo         = overachievement of number of operators allowed.;
Tenders(Operators, Routes):TP, Supply, X;
                  !TP      = tender price of operator O for route R.
                   Supply = Capacity offered by operator for route.
                   X      = 0/1 variable: 1 if operator is assigned to route else 0.;
EndSets
```

```
!In this model, one may wish to add a constraint reflecting the number of vehicles  rather than
the supplied capacity and Total Capacity.  The model may further be changed to allow tenderers
to give fixed rates for operating certain routes and the limit on the number and type of vehicles
they can supply.  The rates might be the same for all routes indicated in which case the tenderer
will simply mark routes in which he is interested.  Owing to the possibility that there is no
solution to the conventional linear model, a goal-program model is a better option;

!Minimise the total cost whilst limiting the underachievement of capacity on each route
 and the use of too many operators on a route.;
Min = @Sum(Tenders(O,R): X(O,R) * TP(O,R))/TotCost
   + @Sum(Routes(R): Supu(R) + Numo(R));

!Subject to:;

!Meet the peak demand;
@For(Routes(R):
         @Sum(Tenders(O,R): X(O,R) * Supply(O,R)) + Supu(R)- Supo(R) = Demand(R));

!Do not assign operators, who have tendered on several routes but cannot actuall operate
 all of them at once, to more routes than they can support.;
@For(Operators(O):
         @Sum(Tenders(O,R): X(O,R) * Supply(O,R)) < TCap(O));

!Limit the number of operators on each route.  (Or make sure that there are enough
 operators.);
@For(Routes(R):
         @Sum(Tenders(O,R): X(O,R)) + Numu(R) - Numo(R) = NumOps(R));

!Set binary variable.;
@For(Tenders(O,R): !X(O,R) = 1 if an operator is to work a route and 0 if not;
         @Bin(X(O,R)));
```

```
Data:
!Normalise the total cost by using the estimated total system cost determined in the
 resource allocation process.;
TotCost = 300; !This number is derived from the resource allocation model.;

!Specify the tender price for each operator for each route.  Set routes not tendered at a
 very high value.;
TP =
!Operator      a       b       c        Route;
               100     75      95       ! 1;
                85     90      105      ! 2;
               999     97      120;     ! 3;

!Specify the capacity offered by a tenderer for a route.  Assumes that more than one
 tenderer is allowed to operate a route.;
Supply =
!Operator      a       b       c        Route;
               100     150     75       ! 1;
               200     320     0        ! 2;
               0       90      180;     ! 3;

!Specify the peak section demand on the route.;
Demand =               !Route;
               175     ! 1;
               300     ! 2;
               180;    ! 3;

!Specify the total capacity of the operator.  (This should really be number of vehicles of
 each type.)Assumes that more than one tenderer is allowed to operate a route.;
TCap   = !Operator   a       b       c        ;
                     300     410     255;
```

```
!Specify the target number of operators or each route.;
NumOps =             !Route;
              2      ! 1;
              2      ! 2;
              2;     ! 3;
EndData
```