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Urban Development:

Use of a

Neural Network Mode Choice Model

Quentin R D Heaney

Thesis submitted to the University of Dublin,

Trinity College for the degree of

Doctor of Philosophy

October 2001

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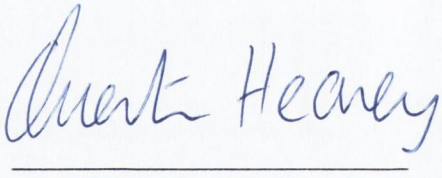

Quentin Heaney

October 2001

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Summary

It is a requirement of the EU that member states undertake the development of urban transport in a sustainable manner. According to the EU the key elements in a sustainable strategy are:

- reduction of the adverse impact of traffic congestion on a city's efficiency,
- increased provision of attractive public transport services.

This thesis examines urban development policy throughout Europe and identifies the necessary components for a more sustainable urban area. From literature it was found that urban density was considered to be the most important factor for reducing car use and increasing the use of environmentally friendly modes of transport – public transport, cycling and walking. It was found that population densities should be above 50 persons per hectare (pph) to begin to impact on the mode choice.

In addition workplace destinations must be located near the central rail stations and a high quality of public transport service should be provided. The whole city's planning strategy must be consistent with this approach and car restraint measures should be introduced to reduce the dependency on this mode of travel. The ability of a city to implement such a coordinated approach depends on its administrative structures. The Dutch coordinated approach to transport and land-use planning was found to be very successful as was the French approach, with its close control over public transport provision.

The development of Dublin has suffered from a lack of coordinated control over land-use and transport planning. New travel patterns have been allowed to develop contrary to transport plans because land-use planners have allowed work places to be dispersed along motorway corridors. New planning structures have the potential to remedy the situation but it is not easy to create a sustainable urban environment when car orientated developments have been allowed to dominate.

The redevelopment of dockland areas provides the potential to create the ideal urban environment. Amsterdam's new docklands and new island developments have the potential to become models for sustainability. The Dublin docklands is studied in detail to provide a case study for the testing of the policy elements suggested.

A neural network mode choice model is developed in Visual C++ that enables the modelling of individual trips and the trip makers in the study area. The neural network approach allows for a large number of explanatory variables to be used and enables public transport to be modelled in a fair and competitive manner alongside private car travel. A neural network's uniqueness is that its internal parameters are adjusted during a training process on representative data. The network can then be run on new data and produce predicted outcomes. In the case of the neural network mode choice model the outcomes are the predicted chosen mode for a particular person for their trip to work in the morning peak.

The data required for training was collected through a questionnaire based survey of the study area. The survey data along with additional data sources was compiled into a Geographical Information System (GIS) which provides the basic data from which the mode choice model is read. Much work was required to convert the input data into a suitable format to enable the neural network to formulate the best model of the mode choice decision process. A development stage followed where different combinations of input variables and network configurations were tested to see how well the model trained and how well the model predicted outcomes on unseen data. Processes and performance measures were developed that allowed different solutions to be compared.

The urban policy strategies were then tested with the model. Population density and the proximity of public transport were found to be important requirements for an improved urban environment. The extent of the benefits achievable by these two strategies is limited by the relative location of workplace destinations. Dispersed workplace locations are difficult to serve with public transport. Coordinated planning of transport and land-use in a prescriptive manner following the policies suggested in this thesis is necessary for an improved urban environment.

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Abbreviations

AO – Autorite Organisatice (French Transport Organisation Body for a conurbation)

BAC – Bus Atha Cliath

BE – Bus Eireann

CBA – Cost Benefit Analysis

CEC – Commission of the European Communities

CIE – Córas Iompair Éireann

CSO – Central Statistic's Office

DABS – Docklands Area Bus Service

DART – Dublin Area Rapid Transit

DDDA – Dublin Docklands Development Authority

dIVV – dienst Infrastructuur Verkeer en Vervoer (Department for Infrastructure Traffic and Transportation)

DLR – Docklands Light Railway

DoE – Department of the Environment

DoELG – Department of the Environment and Local Government

DoT – Department of Transport

DPE – Department of Public Enterprise

dRO – dienst Ruimtelijke Ordening (Department of Physical Planning in Amsterdam)

DRRTS – Dublin Rapid Transit Study

DTI – Dublin Transportation Initiative

DTO – Dublin Transportation Office

DTS – Dublin Transport Study

EIS – Environmental Impact Statement

EPA – Environmental Protection Agency

ERDO – Eastern Regional Development Organisation

ESRI – Economic and Social Research Institute

EU – European Union

EZ – Enterprise Zone

GDA – Greater Dublin Area

GDA – Greater Dublin Area

GDAA – Greater Dublin Area Authority

GIS – Geographic Information System

GMPTE – Greater Manchester Passenger Transport Executive.

GRD – Gross Residential Density

IFSC – International Financial Services Centre

LDC – London Docklands Development Authority

LRT – Light Rail Transit

LT – London Transport

NRA – National Roads Authority

NRD – Net Residential Density

PPG – Planning Policy Guidelines

pph – persons per hectare

PTA – Passenger Transport Authority

PTE – Passenger Transport Executive

PTMT – Public Transport Mode Choice

SPG – Strategic Planning Guidelines

WCED – World Commission on Economic Development

Chapter 1

Introduction

1.1 Background

The World Commission on Economic Development (WCED) first tabled a definition of sustainable development in 1987 as follows:

> *"...development that meets the needs of the present, without compromising the ability of future generations to meet their own needs" (WCED, 1987).*

The Commission had two key issues in mind when they developed this definition. These two issues were:

- addressing the needs of the poor in the world,
- stewardship of the environment so that it has the ability to meet present and future needs.

This definition can be applied to the specific case of urban development. The Commission of the European Communities (CEC) says that urban strategies need to make cities more environmentally sustainable and avoid imposing the costs of development upon their immediate environment, surrounding rural areas, regions, the planet itself or future generations (CEC, 1999). The treaty of Amsterdam establishes sustainable development as an explicit EU objective (CEC, 1999). This will strengthen the requirement for the integration of urban policies in order to achieve more environmentally sustainable cities. According to the EU the key elements in a more sustainable urban development strategy are:

- reduction of the adverse impact of traffic congestion on a city's efficiency,
- increased provision of attractive public transport services with services that are not commercially viable supported by the urban authority.

Some cities have already grasped these principles and accepted that the continued reliance on the private car in the urban environment encourages urban sprawl. Quality

public transport should be provided as an alternative to the private car, in conjunction with focussing on increasing densities and using mixed land-uses (CEC, 1990).

In recent years there has been a resurgence of light rail building throughout Europe. This form of public transport provides a high quality service and can be inserted into an urban environment in a very flexible manner. In the central parts of the city it can wind through pedestrian streets with minimum disruption, providing an immediately accessible attractive service. Then when the vehicle moves out onto dedicated track in the suburbs it becomes more like a train and can move along at speeds of over 80 km/hr.

In order to test the benefits of such a public transport system it is necessary to factor it into the area's transport model. Many cities' transport models focus on the movement of vehicles and so the basic unit is the number of cars travelling on the network. Often the first decision point in the model is between car and public transport. The public transport values considered are a log-sum average of the various modes available and so there is no consideration of the individual benefits of a quality public transport route that may be available.

The majority of transport models do not consider walking or cycling in the main model. In the case of Dublin walking and cycling is factored in as a declining mode over time. It is considered that to investigate sustainability policies these modes must be catered for at a comparable level.

1.2 Aim

This thesis will seek to show the importance of the co-ordination of transport and land-use planning in successfully implementing improved urban development strategies. The necessary components of such a strategy will be compiled by examining the experience of a number of study cities. The development of Dublin will also be closely examined to see whether its planning has been in line with such a strategy. Dublin's docklands area will be closely examined and used as a test area for the developed policies.

A new type of mode choice model will be formulated based on a backpropagation neural network. This model will enable the travel decisions of the study area's resident population to be examined on an individual basis. As a result public transport, cycling and walking will be modeled at a similar level of significance to the private car. Elements of urban policy will be evaluated through the development of test case future scenarios.

1.3 Research Approach

Wide ranging types of approach were required in this work. Initially a literature based study was required to investigate the various planning practices throughout Europe. Some select examples were also included from outside Europe. A more detailed examination of public transport and land-use development was undertaken in some of the cities. Where possible cities were visited and information collected both through interviewing key people and observation. The elements required to create a more sustainable urban environment were developed from this work. The compilation of information for the analysis of the development of Dublin was undertaken using literature, interview and observation.

Literature based study was also required for the theory behind neural networks and mode choice models. It was then necessary to develop the algorithms and C++ code necessary to integrate the two theories. A system of databases were used for input and output of data.

The necessary data from the study area was collected from a number of sources. A questionnaire based survey was undertaken of the area to get information on individual trips and trip makers. This data was supplemented by the Small Area Population Statistics (SAPS) from the censuses (CSO, 1991 & 1996), DTO (1996) origin destination data and Thom's street directory (Thom's, 2000). A geographic information system (GIS) was used to integrate the data with its spatial information. This was then converted into the required database form.

An extensive testing program was required to develop the neural network mode choice model. This required testing of internal and external parameters of the model. Measures of performance were developed so that the different versions of the model could be compared and the best chosen.

Data for the future development of the area was compiled from current planning applications and Dublin Docklands Development Authority (DDDA) aspirations. This data was then used as the basis for tests on future year scenarios. These future year scenarios provide the basis for analysing the benefits of the urban development policies that were developed.

1.4 Outline of Thesis

The first step in tackling the problem posed by the title is to put forward a theory of how a more sustainable urban environment can be achieved. ***Chapter 2*** approaches this firstly by presenting a discussion of published research and then through the examination of cities, their planning systems and how they actually perform. The redevelopment of some dockland areas is examined to compare and contrast the different approaches used. Finally a list of steps that assist in achieving a more sustainable urban environment are postulated.

In ***Chapter 3*** a detailed analysis of the development of Dublin is presented. This includes a look at the planning processes that have shaped Dublin and a discussion of the proposed new planning and administrative structures. Information is presented showing how Dublin has changed over the last 10 years and some conclusions drawn as to why the changes have taken place in the manner that they have. The Dublin docklands area is discussed in light of the fact that part of this area will be used as the study area for this work.

Chapter 4 presents the theory required to develop a mode choice neural network. Firstly the theory behind neural networks is presented. Then the different types of mode choice models in common use are discussed. The formulation of a neural network in an object-orientated manner in C++ code is presented. A short overview of

where neural networks have been used in transportation previously leads into the explanation of how a neural network can be used as a mode choice model. The development and application of a pilot mode choice model is presented. This is followed by a discussion of the benefits of such a model.

In ***Chapter 5*** the mode choice model is developed on the survey data from the chosen study area, which is a sub-section of the Dublin docklands. Some detailed information on the study area is presented to set the background. The development, administration and analysis of a questionnaire based survey of the study area is presented. The steps required to compile this data, along with additional data into the required form, are outlined. It is then possible to run the neural network mode choice model. The first stage testing is presented and discussion follows.

In ***Chapter 6*** the model is applied to the study area. The steps required to collate the data into the required form are presented. Information is presented on the possible future development of the area both in terms of public transport and land-use. An evaluation of a series of test runs and sensitivity tests is then undertaken to select the best model configuration.

A series of future scenarios are presented in ***Chapter 7***. Different public transport options are tested followed by tests on population density and complementary policies. The benefits of these policies are evaluated and discussed. The performance of the model is then evaluated.

Chapter 8 contains final discussion and conclusions of the work and some suggestions for further work.

Chapter 2

Coordinated Planning of Transport and Land-use: A Requisite for a More Sustainable Approach to Urban Development?

2.1 Introduction

Planning mechanisms for transport and land-use have to some degree, over time, developed independently in many countries. This is in spite of the inherent interdependence of the two areas. Subsequent sub-sections will show the impacts that the two disciplines have on each other. In simplistic terms the impacts are:

- land-use decisions lead to new developments which give rise to new trip patterns creating new transport demands, and
- transport decisions have an impact on the preferred locations for new developments in the eyes of both the land-use planners and developers.

These connections between the two disciplines are so important that they should dictate the shape of the planning process. It could be said that the first connection is already utilised since traditionally one of the main functions of a transport planner is to look at where the transport demand is being created, predict where future demand will be, and plan for this. This is often termed "predict and provide". The second connection is sometimes made where the land-use planner seeks to encourage new developments at locations with good transport links, such as motorway interchanges or near railway stations.

Allowing decisions to follow on from each other in a cause and effect continuum can create a never-ending spiral of increasing transport demand and urban sprawl. Such a process would not lead to a sustainable urban environment. It is a process that is driven by market pressures and is only regulated in a limited manner. To achieve a more sustainable urban environment the decisions made relating to transport and land use should complement each other. Indeed planning and transport planning should be integrated into all levels of policy making so as to ensure that all the decisions made are consistent with each other (RCEP[1], 1995).

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[1] Royal Commission on Environmental Pollution

The proper planning of an area would involve stipulating the type and quantity of development and what form of transport provision should be made. This in effect can provide a form of demand management. A key measure of the success of such planning is the level of trip making by different modes as well as the overall level of trip making. A key objective arising out of the definition of sustainable development is the reduction in use of non-renewable energy sources. At present the vast majority of private cars run on either petrol or diesel power. However the technology is arriving that will provide for more environmentally friendly cars. The new Toyota Prius is a case in point where it combines a traditional engine with an electric motor. In the long term, the private car will become environmentally friendly in terms of its emissions at point of use.

A zero emissions car will still face the fundamental problem of modern day travel in urban areas – congestion. Demand for travel in urban areas is increasing such that there will not be sufficient road space for everybody to travel in their personal car. An average European citizen travelled 31.5 km per day in 1993 compared to only 16.5 km per day in 1970 (EC, 1996). This growth in demand has been largely met by the use of private cars, which now have a 75% share of distance travelled (EC, 1996).

The following objectives can be proposed as being necessary for a more sustainable urban environment:

(i) reduction in trip distances,

(ii) reduction in number of trips,

(iii) reduction in car dependency,

(iv) increased use of environmentally friendly modes of travel.

Individually these objectives can be achieved by a variety of means but a fundamental requirement is that people's quality of life should be maintained and preferably improved. Improvement of public transport will benefit greatly those who don't have access to private cars. No matter how high the levels of car ownership reach there will

still be people who can not use a car for various reasons including age and disability. Some of these people's quality of life would be improved by the provision of level access public transport in preference to space for the private car.

The first step in this sub-section will be to investigate the theoretical ways of achieving a more sustainable urban environment. Following on from this the thesis will focus more closely on a number of specially chosen cities. First of all the transport systems in the selected cities will be compared. The next section will then focus on the planning and development of light rail systems. Where co-ordination of transport planning and land-use planning occurs in any of the study cities it will be highlighted.

Subsequently an investigation of three redevelopment/development areas will be presented. Studying such areas allows the transport and land-use planning processes to be seen very clearly. Three cities with large scale developments taking place are:

- London Docklands,
- Manchester → Salford Quays,
- Amsterdam → Eastern Harbour and IJburg.

2.2 How to achieve a more sustainable urban environment.

Newman and Kenworthy (2000) conclude that a city can not be considered sustainable if the majority of people are dependent on the use of their car. Such dependence is usually a function of the city's urban form and level of public transport provision. The mobility of people who do not have access to a car in such a city is significantly reduced compared to the rest of the population. The European Commission estimate that 40% of European households do not have private cars (EC, 1996).

The European Commission goes on to state what the solution must be:

"Nevertheless if further consequences for our quality of life and for the environment are to be avoided then the development of public passenger transport systems must be given greater priority as part of an integrated approach." (EC, 1996).

So first of all, this thesis will investigate public transport policy. Following on from this the two-way interaction between transport and land-use will be investigated. The focus will be on identifying how to utilise the interaction to help to achieve the stated objectives of reducing trips, reducing trip distances and achieving a shift away from car use to environmentally friendly modes. Additional complementary planning measures aimed primarily at reducing car use will be investigated.

This theoretical review will then enable a hypothetical strategy for an improved urban environment to be tabled.

2.2.1 Public Transport Policy

A key part of any transport policy is the relative position that public transport and other alternative modes are placed in the hierarchy of transport modes in the city. Many European cities still give the private car 'pride of place' in the central areas whilst claiming that the city is a supporter of public transport. It is necessary to make public transport more attractive and usable to reduce the growing car dependency. According to the European Commission public transport must become more flexible and better suited to meeting the needs of its users (EC, 1996).

The construction of extensive metros in large cities is often necessary to provide sufficient capacity to service the central area. Cities such as London and Paris built such systems many years ago, providing fast and efficient public transport service through out the city. These systems are expensive and London is currently in a difficult situation where much investment is required to maintain and improve the network. This has to be done whilst providing an essential service to the trip makers.

Underground systems leave surface space available for other modes such as the private car. In fact, this is often a key argument why public transport should be put underground. Rarely is additional surface space provided for pedestrians and cyclists. There are some exceptions to this – Amsterdam is one such city. In Amsterdam the main street leading away from the Central Railway Station has two tram lanes, two cycle lanes and two lanes for private cars as well as footpaths on either side of the street

for pedestrians. In reality pedestrians can spread over the tram tracks as the tram movements are predictable and familiar to the people.

Many people are not comfortable travelling underground. There is a new school of thought that wishes to place the public transport on the surface and remove the cars from this environment. This both results in improved public transport and traffic calming measures which divert the private car away from the city centre. Light rail provides an attractive surface option, giving the user direct access to the environment through which they are travelling. The choice of light rail displacing the private car is a clear indication that a city's policy is pushing the private car down the hierarchy.

The two key determinants for a public transport system to be successful are:

- competitive travel time compared to other modes, and
- predictable and consistent journey time.

Public transport systems will only have competitive, predictable and consistent journey times if they are given priority over other modes. It is essential that a light rail vehicle or bus does not get delayed in the same traffic as a private car. Newman and Kenworthy (2000) show that European and wealthy Asian cities use public transport considerably more than their American and Australian counterparts. The authors also show that it is only in these cities that public transport has a higher average speed than the car.

A number of other issues considered important for the development of successful public transport are:

- Easily accessible by private transport including walking and cycling. Car parks should be provided at outer stations and sufficient bike parking should be provided throughout the network.
- Integrated ticketing should enable people to buy a single ticket that allows them to transfer between modes during one journey.

- Real time information available so that people can reassess their travel choices before and throughout their journey.

The next section will investigate how to maximise the benefits of public transport investment for urban development.

2.2.2 Impacts of Transport Investment on Land-use

The link between the development of new public transport services and changes in land use can be manifest in many different ways. A definition for "transport impacts on land use" was proposed by Still et al. (1998) to be:

"...any alteration to the distribution of urban, social or economic development caused by transport policy".

The principal indicators of these changes are either economic or social/demographic. Researchers in many different countries have endeavoured to evaluate these indicators. Even when the indicators are successfully evaluated the decision as to how much of the change can be attributed to the new transport policy is a complex issue. Transport investment does not take place in a vacuum, and in a living place there is usually much going on that impacts on the interaction.

In an inaccessible area the impact of new transport policy will be more substantial. Accessibility is essential for all forms of economic activity. Good accessibility is not a sufficient condition for economic stimulation but is part of a strategy. For public transport to stimulate economic activity Simpson (1994) says that two conditions must be met.

1. The traveler must see public transport as offering advantages over the other forms of access.

2. The other conditions for economic activities must also be satisfied, such as demand for goods and the competitiveness of the locality.

Rail investment in a congested corridor results in an increased capacity of the whole transport system and creates a situation which allows economic growth (Dickens, 1992). Different types of public transport have different levels of influence on their surrounding area. Dickens (1992) stresses that LRT investment 'enables' growth rather than actually promoting it. Thus LRT investment will enable developments to occur in and around stations.

It is difficult to directly link land use effects with urban rail development. Indeed Simpson (1994) says that the evidence that light rail schemes will stimulate land use changes is unconvincing. He says that this uncertainty is highlighted by the difficulties in getting developers to invest in a rail system. On a more positive note, Dickens (1992) shows us that in 1960, in Toronto, 90% of all new office developments took place along the metro lines. In addition 48% of all new apartments were built along the metro lines. Dickens also quotes the President of the Real Estate Board in saying:

"If an urban rapid transit system never earned a dime it would pay for itself a thousand times over through its beneficial impact on real estate values and increased assessments".

In Dublin, MacLaran (1993) says that there has been a distinct movement in the location of modern office developments into the areas to the east of Westland Row. This area is close to Pearse Station, which is on the DART urban rail service. According to MacLaran this change of land-use in the area from industrial, institutional and residential land-uses is due in the main to the implementation of the DART service in 1984. Of course, as shown already, other conditions had to be right but that the provision of an improved rail service 'enabled' the growth to take place.

In contrast the Tyne and Wear Metro was developed at a time when the economy in the Newcastle area was in a depressed state. As a result the new rail system did not have any significant impact on office or industrial location. This supports the second of Simpson's (1994) conditions for public transport, that to stimulate economic activity the local economy must be competitive. At the time of implementation of the Metro the economy in the Newcastle area was in a depressed state. Walmsley and Perrett

(1991) conclude in their research that rail investment can "accentuate existing trends". By this they mean that if there is a demand for property then rail investment can accelerate the expansion of the area.

A number of pieces of research (Dickens, 1992, Cervero, 1984, Dueker & Bianco, 1998, ECOTEC, 1993) agree that the impact of rail investment on land-use can be great, especially if complementary policies are used in conjunction with the development of light rail. Dickens (1992) confirms that no complementary planning policies were pursued to promote development near the Tyne and Wear system. Cervero (1984) says that a new light rail line must be integrated with local pro-development policies. He says that the following policies are important for encouraging development in and around station areas:

- land zonings,
- special taxation incentives,
- joint development incentives,
- strong regional economy,
- traffic restraint measures such as parking controls or road pricing.

Dickens (1992) concludes that the following are also beneficial:

- investments from land use developer in system,
- cross-party political support for system so that developers feel that there is long term commitment.

Involving property developers is important, as they will be the primary movers in developing the land in and around the new system. Joint developments allow greater control by the authorities over what is built where in relation to a station. It allows some of the risk to be carried by those involved with the success of the public transport scheme. This helps to instill confidence in other developers of the merits of developing

in the area. Where the system will bring large benefits to a development it is reasonable to expect the developer to contribute towards its construction.

Heavy rail is generally assumed to have a zone of influence around its stations of about 500m. Cervero (1984) suggests though that LRT's sphere of influence would be less than heavy rail. This might be down to around 350m (quoted as one or two city blocks) at most. Dueker and Bianco (1998) point out that there are in fact two opposing effects that impact on residential property values near a LRT station. On the one hand the property values are increased due to the improved accessibility whilst, on the other hand the nuisance effects of increased noise, traffic and pollution may decrease values. Their research shows that the effect of improved accessibility dominates the negative nuisance effects. Using data collected on the eastside rail corridor in Portland, USA, Dueker and Bianco (1998) show that the value of a single-family house decreases significantly with distance from a light rail station . Figure 2.1 presents this data in the form of a graph, which clearly shows how the house prices rise dramatically as they approach an LRT station. A house valued at $82,800 right beside an LRT station would only be worth $74,835 1,000 feet away.

This positive influence of urban rail is supported by an Irish example published in the Irish Times (IT, 10/12/00). A detached four bedroom home in Rowanbryn, Blackrock, Co Dublin was for sale in September 1983 for £45,000. The DART suburban rail service began running in the summer of 1984. In September 1984, two months after the DART had started running a four-bedroom house in Rowanbryn was priced at £49,500. By September 1986 houses in Rowanbryn were priced at £57,000, a 40% increase on the pre-DART price. There was only an average increase in residential property prices in Dublin of 10 to 15% in the period 1982 to 1987.

From the above research, it is possible to conclude that investment in rail based public transport systems can impact positively on the surrounding environment. Rising property prices will encourage developers to maximise the development opportunities in the vicinity and so increase the economic activity in the area. For such activity to

occur and be facilitated by public transport, a number of other conditions are necessary. These are:

- system should offer a quality service so that it is an attractive option to other modes,
- local and regional economy should be relatively buoyant,
- the system development must be integrated with pro-development policies,
- complementary transport policies.

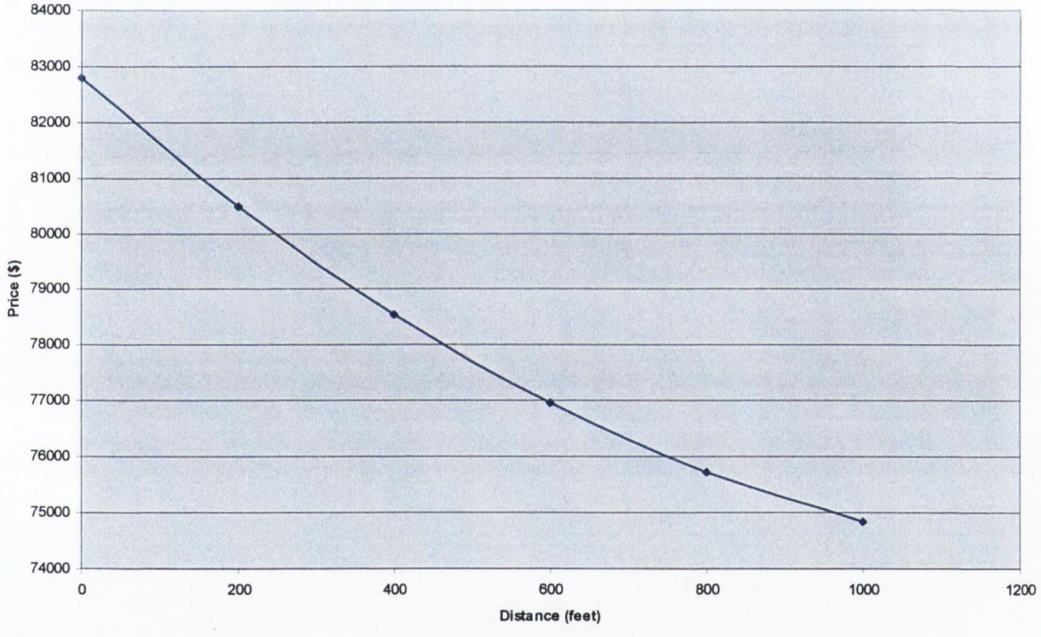

Figure 2.1: Price Effect on Single-family Housing in Portland, USA (Source Dueker & Bianco 1998)

When a system's impact is maximised in such a manner then the development patterns that occur should be conducive to a large proportion of travel being catered for by public transport. The development of Paris and London over the last century has been impacted greatly by the urban rail systems in place.

The location of developments also impacts greatly on the transport requirements of an area. It is necessary to look closely at the relative location of different types of development so that the four objectives are met. Public transport routes should be planned so that the pro-development policies will enable developments to take place that are conducive to public transport travel. The next section will investigate what development patterns will produce the most sustainable travel patterns.

2.2.3 Impact of Land-use Patterns on Patronage

Breheny (1996) proposes that the development of urban form can be split into two groups of thought, centrists and de-centrists. The centrist theory supports the concentration of development in cities leading to higher densities. This type of development more readily supports mass transit systems and city centre car travel would be actively discouraged. In fact research shows that centralisation increases the use of public transport and reduces use of the car for travel to work (ECOTEC, 1993). De-centrists are said to be made up of 'free-marketeers', who say that market solutions will optimise urban forms, and 'good-lifers', who argue for decentralisation.

It is the theory of centralisation that is academically popular. According to Breheny (1996) centrists claim that higher density urban living is compatible with a higher quality of life. This higher quality of life would arise from reduced air and noise pollution due to a reduction in car travel. It would also help to reduce the level of fuel used in the transport sector. Newman and Kenworthy (2000) show that very strong correlations are found between the level of car use and:

- the level of public transport provision,
- public transport speed to traffic speed ratio,
- parking provision,
- urban density.

Of these factors the authors say that urban density has the greatest impact on reducing car use.

Some cities such as Toronto and Montreal have allowed the residential areas of their cities to expand (Walmsley and Perrett, 1991). In the case of Toronto the developments have been concentrated around the rail stations whilst in Montreal this has not been the case and a huge increase in car commuter traffic has occurred. This shows that there may be a case for a city to expand its residential area as long as it is focused on quality public transport links. The negative aspect of such a policy is that trip lengths will increase relative to a compact city.

The focussing of residential development around rail stations means that an increasing number of people will live within easy walking distance of the station. This proximity to a station is a fundamental incentive for commuting by rail. Cervero (1994) shows that in California residents living in Los Angeles near BART rail stations were around 5 times as likely to commute by rail as the average person who lived and worked in Los Angeles was. Certain complementary policy measures are required so that the positive effect (increased public transport patronage) of concentrating more housing around stations is maximised. Cervero (1994) suggests that if workplace destinations are scattered throughout the urban area then such housing developments will not result in increased public transport use. The corollary to that is that workplace destinations need to be concentrated in a small number of zones so that they can be directly served by public transport. So in summary the two key factors for increasing public transport usage are:

- Residential housing density,
- Trip destination near a rail station.

The next step will therefore be to derive some guideline figures for the necessary residential housing density. Figure 2.2 shows the average distance travelled by person according to their mode and the density at which they live. The living density is given as the number of persons per hectare. In general a rural area would have a low living

density whilst an inner city apartment development would have a high living density. In Figure 2.2 it is apparent that for those who travel by car there is a significant fall in distance travelled as the living density rises. People living at a density of less than 1 person per hectare travel on average 160 km per week by car whilst people at a density of > 50 persons per hectare will only travel on average 80 km per week. This means that people living in a low-density environment in Britain travel more than twice as far by car than those living at higher densities.

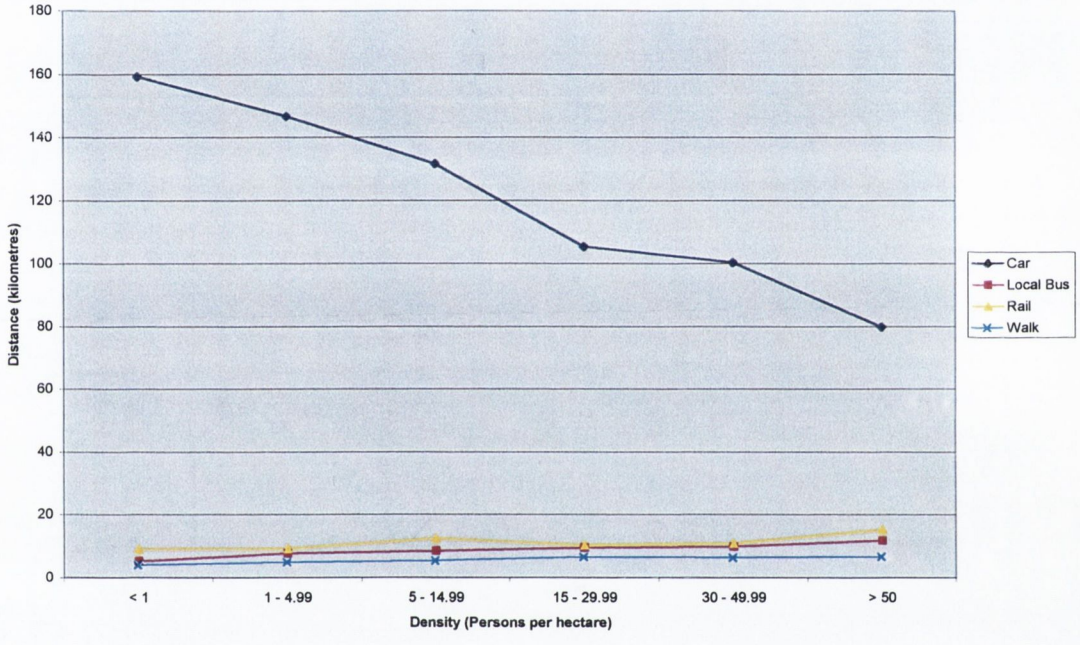

Figure 2.2: Distance Travelled per Person per Week by Mode and Population Density. (Source: ECOTEC, 1993)

Looking closely at Figure 2.2 it can be seen that the weekly travel distance drops quickly until it reaches the 15 – 29.99 person per hectare range and then stabilises through the 30 – 14.99 persons per hectare range at approximately 100 km per week. This shows that there is a significant benefit in keeping densities above 15 persons per hectare. Where car use is to be dramatically reduced densities should be above 50 persons per hectare.

The other modes show less of a change as density changes but Figure 2.3 shows the same data excluding the car data so as to provide a close up picture of the other modes.

Interestingly it shows that they all have a generally increasing trend in opposition to the car data's decreasing trend. The most significant increase in distance travelled by bus and rail occurs once densities are over 50 persons per hectare. In the case of bus and walking the distance increases up until a density of 15 persons per hectare has been reached and then stabilises up until the density goes over 50 persons per hectare.

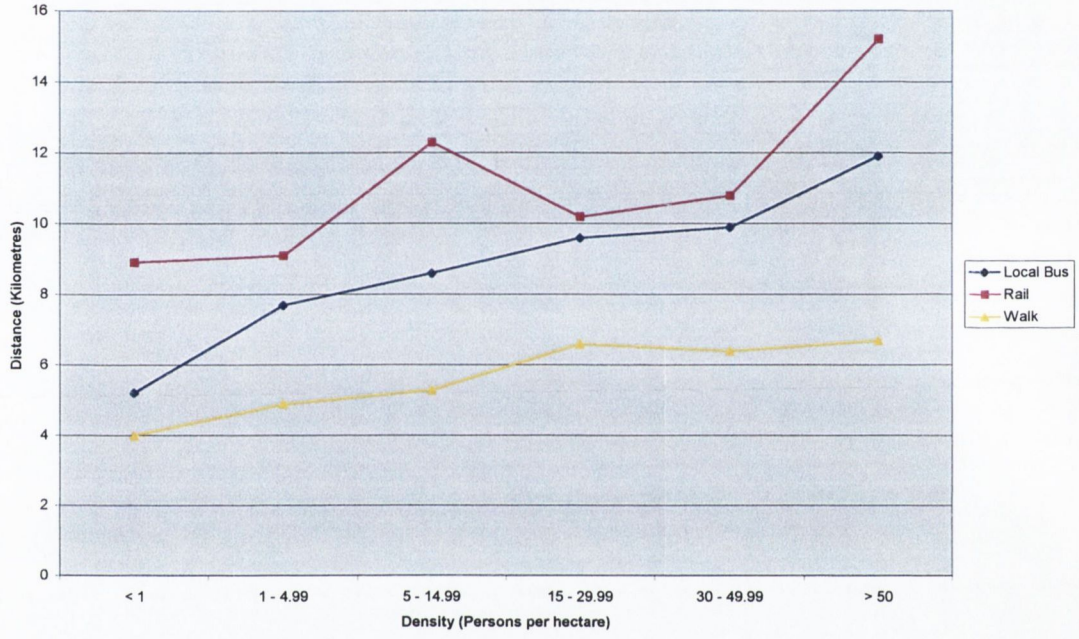

Figure 2.3: Distance Travelled per Person Excluding Car. (Source: ECOTEC, 1993)

Rail shows an unusual trend in that there is a big increase in distance travelled for the 5 – 14.99 range before decreasing for the two ranges encompassing 15 – 49.99 persons per hectare. It is assumed that this anomaly occurs because people living in a less densely populated area will travel to a rail station to travel by rail for a relatively long distance to work in a city or large town. As the living density increases then it is likely that the distance to travel to work will be less and so statistically the average distance travelled per week decreases. The large increase in rail and bus when the density is over 50 persons per hectare is due to the increased use of such modes for many different trip purposes. This supports the theory that higher densities encourage travel by public transport. It follows then that any urban area needs a certain level of residential density to warrant public transport investment.

In fact Cervero says that the size of the central business area and the residential densities are the two most important factors in determining whether an LRT investment is warranted (Cervero 1984). He gives outline figures as follows:

- central business area with about 2 million to 5 million square metres of floor space,
- residential densities of about nine housing units per residential acre in a corridor of about 60 to 250 square kilometres (assuming house occupancy of 2.5 – 3.0 this is equivalent to 55 – 65 pph[2] GRD[3]) .

Table 2.1 shows some suggested residential density levels.

Optimal	*GRD (pph)*	*NRD[4] (pph)*	*Source*
Public Transport	30 – 40	90 – 120	Newman & Kenworthy (1989)
	55 – 65	165 – 195	Cervero (1984)
Walking	100	300	Newman & Kenworthy (1989)
Sustainable Urban	75 – 100	225 – 300	Friends of the Earth cited in Fulford (1996)
Central/Accessible Urban	Up to 120	Up to 370	Friends of the Earth cited in Fulford (1996)

Table 2.1: Suggested Residential Densities. (Shaded cells are estimates assuming NRD is three times GRD)

[2] pph: persons per hectare

[3] GRD (Gross Residential Density): population divided by geographical area

[4] NRD (Net Residential Density): excludes open spaces and non-residential land

Newman & Kenworthy (1989) suggest that for public transport use the density should at least be in the region of 30 – 40 pph GRD. In their view this must rise to 100 pph to create an optimum environment for walking. With reference to Table 2.1 again Friends of the Earth consider that these high densities are desirable for a sustainable urban environment. They recommend 75 – 100 pph for a sustainable urban area and rising to 120 pph in central urban areas.

Undoubtedly, as the density of people in an area increases, it becomes easier to provide high quality public transport for the area. What is not clear though is whether people are receptive to the idea of living in close quarters with so many others? In some cultures, as Table 2.2 shows, high-density residential developments are widespread, whilst in countries such as Ireland and the UK such developments are scarce. The GRD in London is 56 pph, which is high when compared to Los Angeles (20 pph) and Melbourne (16 pph) but tiny compared to Hong Kong (293 pph) and Tokyo (105 pph).

Existing	*GRD* *pph*	*NRD* *pph*
Hong Kong	293	879
Tokyo	105.4	316.2
London	56	168
Paris	48.3	144.9
Toronto	39.6	118.8
Los Angeles	20	60
Melbourne	16.4	49.2
England (new residential)		47-94
Milton Keynes		67.5

Table 2.2: Comparison of Residential Densities (Source: Fulford 1996)

This acceptance of high residential densities by the public is crucial to the success of a "compact city" policy. The real question is what is the optimum density that will provide sufficient users for public transport and still be acceptable to the general public. High-density urban living may be acceptable for childless couples and singles in their 20s and 30s but it is possible that when people have children they will seek to move out into an environment with more open space. This would mean that the population of the inner part of a compact city would always consist of a particular age segment of population. A positive aspect of this would be that the travel patterns would stay more consistent. It would be important though that a variety of housing types were available within the urban area to cater for the whole population.

In conclusion then for rail investment to be successful it would appear that a GRD of 30 – 65 pph is required. Densities of greater than 50 pph would appear to provide significant returns in terms of public transport usage. Even greater residential densities may provide long term sustainable solutions but whether they are socially acceptable is another issue.

The second factor, the location of workplace destinations, is dependent on a wider land-use policy objective for the region. It has been shown that the centralisation of such destinations provides the greatest number of commuters travelling by public transport. This concentration of workplace destinations is in line with the concept of the compact city. Cervero (1989) points out that in single land-use work environments the car is essential for accessing services such as restaurants, shops and banks. This means many people will travel to work by car so that they can access these facilities at lunchtime or after work. People are more likely to travel to work by public transport if they work in a mixed land-use environment where they can access these services by foot or bicycle (TRI-MET, 1996). Breheny (1992) says that following a policy of mixed land-uses is imperative in creating a more sustainable urban environment. Once residential developments are also included in the mix then there is the possibility that people will choose to live and work in close proximity, resulting in a further reduction in travel.

Through centralisation and mixed land use there should be an increase in the number of facilities that can be reached within convenient walking times and a reduction in the need to travel elsewhere. In addition, the density of trip ends should be high enough to support quality public transport. The provision of quality public transport improves the accessibility of the central location and makes it attractive for developers.

Complementary transportation planning measures are required to maximise the effect of the two principal land-use measures. Cervero (1994) says that in order to maximise the benefits of the policy of locating housing around stations then car restraint measures must be introduced. Such measures will be investigated in the next sub-section.

In summary this section has shown the importance of regulating the type of development that is allowed to take place in the area surrounding a rail station. This can successfully influence the number of people who choose to commute to work by rail. Two factors are deemed to impact significantly on the rail travel figures:

- residential density around rail stations should be greater than 50 pph,
- workplace destinations concentrated around central stations,

2.2.4 Reduction in Car Dependency

The majority of policy makers now agree that it is necessary to substantially change the car-orientated policies for their cities. Up until the mid-1960s Hall and Hass-Klau (1985) show that Britain and Germany had attempted to provide extra highway capacity for the rising numbers of cars. It was at this point, they say, that the planners realised that applying such a policy to cities was self-defeating and environmentally destructive. The new policies were based on traffic restraint and improving public transport.

Bratzel (1999) says that even though this fundamental policy development is now widely recognised, many European cities have failed to fully implement the required measures over the last thirty years. He goes on to suggest that the biggest obstacle to this is the political process. This is often magnified by changes in government, which can result in changes of direction in transportation policy.

Reducing car dependency is a worthwhile policy in its own right but here it is being investigated as a complementary policy to land-use planning that has as its aim to increase the usage of public transport. Cervero (1994) in his research on land-use and public transport usage also finds the following factors to be important in determining if people travel by public transport:

- car availability,
- availability of free parking at destination,
- employer-paid public transport passes.

In general car availability will increase with increasing wealth. Increasing car use is often thought to be the inevitable side effect. New research by Newman and Kenworthy (2000) shows that increasing wealth usually results in increase car ownership levels but not necessarily increased car dependence. They cite two examples:

- The car is used considerably more in US and Australian cities than in European cities but European cities are wealthier,
- Developing Asian cities have higher car use than the three wealthiest Asian cities.

It is necessary to factor car availability into any study but it does not necessarily follow that a reduction in car availability should be targeted in any policy developed. Instead car dependency should be targeted and peopled should be encouraged to choose the right mode for the right trip. The car is an incredibly flexible mode of transport and allows journeys to be taken directly from origin to destination quickly and in comfort. According to Perry (1989) problems only occur when:

- parking is not available close to the destination,
- congestion leads to journey times becoming unacceptably long or unpredictable,

- perceived cost of travel by car is greater than by an alternative mode.

It is due to these problems that sustainable alternatives to the private car for urban travel are required. Focussing on these very problems, that arise out of high levels of car use, can enable car dependency to be reduced. A reduction in the supply of parking and road space allocated to the private car will inevitably reduce car dependency in that location. Adjusting the relative travel costs between car and other modes so that car is less attractive will also help to decrease car use to that area. One method of adjusting the travel cost so that public transport is more attractive is through, as mentioned above, the provision of employer-paid public transport passes.

O'Flaherty and Coleman (1997) say that car-parking policy has a significant impact on the reduction of car use and places it above policies relating to urban form. He puts forward the seemingly logical suggestion that where employment developments are well served by public transport, developers should be restricted to supplying a smaller number of parking spaces. This supports the conclusions arrived at in the previous section that to maximise the benefits of public transport orientated development, parking limits should be set. This policy must be carried through to its logical conclusion in that competing peripheral areas are not allowed an unfair advantage. Consistent limits on overall car-parking provision should be agreed at a strategic level covering potentially competing central and peripheral areas (ECOTEC, 1993). Inconsistencies in this will allow a shift in the focus of development away from the city centre to peripheral locations.

The development of park-and-ride sites can make it possible for people travelling from areas without public transport to transfer to public transport for the urban part of their journey. If development of such facilities is done in parallel with the reduction of city centre parking then car-km should reduce. The danger lies in providing park-and-ride whilst city centre parking remains at the same level. There is a latent demand for car trips that is suppressed by availability and cost of parking. Park-and-ride can also encourage people to commute to a city from further away. In order to maximise the reduction in car travel associated with public transport it is best if the majority of

people live within walking distance of a station. This focuses back on the previous section where it was concluded that residential developments should be concentrated around public transport stations. Rising land values and pressures for affordable housing have forced BART to seriously consider converting parts of its park-and-rides to mid-rise housing (Cervero, 1994). This would assist in focussing housing developments near to stations.

Congestion also suppresses demand for car use. People choose to make only absolutely necessary journeys during periods of congestion. As such congestion is self-regulating in many cities it tends to stop short of reaching an intolerable level (RCEP, 1995). There are other side effects though of allowing congestion to be self-regulating. In the short term it suppresses car demand but in the longer term people will be likely to change the starting or end point of their journey. 'Edge Cities' in the USA are the extreme example of the way many European cities are beginning to develop.

Some other side effects of congestion include:

- stop-start driving conditions reduce fuel efficiency and increase emissions (RCEP, 1995),
- bus based public transport systems often get caught up in the congestion,
- time lost to businesses when people or goods are delayed by congestion,
- unpredictable journey times causing frustration,
- incidents on highly tuned road networks cause chaos that is widespread and takes a very long time to disperse (Perry, 1989)

Reducing road space available for the private car also has the potential to reduce car dependency. A reduction in road space can take the form of car-free zones where only pedestrians, cyclists and possibly public transport are allowed. It can also mean a reallocation of car space to dedicated public transport lanes. Traffic cells are a coordinated approach to reducing car traffic. This is where, through a system of

banned turns and car-free zones, it is impossible to drive through a traffic cell. As a result the only traffic in the cell is traffic that actually has business within that cell. Successful traffic cell strategies exploit the reduced access for the private car by improving public transport and pedestrian access along the very routes that car access has been limited. In fact if access is not provided by public transport or through improved pedestrian links then people and businesses may well relocate to avoid the congested location.

A topic that has received much debate recently is congestion pricing. In an urban situation this might take the form of charging people on entering a central zone. The aim of such pricing is that a car user would pay for the cost that is imposed on the environment and other travellers by making that journey. This means that there is greater economic efficiency as each individual pays for the external costs of the journey made. Such a policy would also help to make public transport more attractive in relative cost terms. In many European cities the principal delay in implementing charging has been due to the political process. The politicians are fearful of implementing a policy that is perceived to be universally unpopular.

2.2.5 Other Issues

The priority given to pedestrians in a city is usually derived from the policies relating to urban form and transport. In a compact and public transport prioritised city, pedestrians are generally allocated more space. Pedestrian priority was highlighted as an integral part in any car restraint measures such as traffic cells. A compact and centralised city naturally gives rise to more destinations being within walking distance.

Hall and Hass-Klau (1985) say that the German cities pedestrianised their central shopping districts resulting in a network of pedestrianised streets whilst British cities have only pedestrianised one or two streets. As a result a German city is less car-orientated than a British city. This is also due to the fact that the rail based public transport systems can bring the people into the city without their cars. When rail based public transport systems are implemented then it is often found to be more acceptable

to introduce traffic restraint measures such as parking and pedestrianisation (Walmsley and Perrett, 1991).

It is also possible to integrate the development of light rail with pedestrianised areas. Cities such as Sheffield, Manchester and many continental cites have shown that pedestrians mix easily with light rail vehicles. The well defined swept path gives confidence to the pedestrians. Well designed pedestrian projects provide a safe and attractive environment for walking and reduce the conflicts between pedestrian and vehicular traffic (TRI-MET, 1996).

Pedestrianisation allows people to commute into the city by public transport and then move around freely with limited conflict with traffic. This reinforces the case mentioned earlier for a mixed use environment. In a central location with its mix of facilities and good pedestrian access people don't need a car for lunchtime and after work leisure activities.

An issue that must not be overlooked is the importance of providing facilities for cyclists. Again a natural function of a compact city is that many facilities will be within cycling distance. A city aspiring to be more sustainable should provide segregated cycle routes throughout the urban area. Secure cycle parking is also essential, as are shower facilities at work.

The aims set out at the beginning of this chapter focussed on reducing trips and encouraging the use of environmentally friendly modes. A measure that has benefits for peak period congestion that has been implemented in some work places is flexible working hours. An employee can choose when to start work, typically anytime between 7 and 10 am with the total number of hours worked in a week or month being the required measure. Perry (1989) points out that due to the nature of certain businesses the nine to five working day will continue for many. In addition what this measure does is spreads the peak over a longer period of time and does not necessarily address any of the key aims in creating a more sustainable urban environment.

2.2.6 Measures for a More Sustainable Urban Environment

A large series of measures have been identified which are necessary as part of an integrated strategy of coordinated transport and land-use planning. An improved solution cannot be achieved without coordinating all of the elements. The key elements identified include:

- Urban density is the single most important factor in reducing car use,
- Residential densities should definitely be above 15 pph but to reduce car use and increase public transport use densities should be above 50 pph,
- These high residential densities should be focussed around rail stations,
- Workplace destinations should be concentrated around central stations,
- Central area should consist of mixed land-use and have good pedestrian routes,
- Public transport system must be attractive compared to other modes in terms of travel time and consistency of travel times,
- Complementary transport policies such as a strategic parking and road space strategy.

2.3 Planning Mechanisms for Transport and Land Use

2.3.1 Introduction

Although numerous factors have directed the planning of cities throughout the world, three are fundamental to the development of urban form through to the current day. History, geography and cultural tradition can describe most of the development process of any urban area.

Often the form of our cities reflects the transport technologies that were dominant at different historical stages of their development. Wars, particularly during the 20th

century, have meant that certain cities redeveloped their street pattern when rebuilding. Cities have often displayed a preference for certain types of development giving rise to different densities. The geography of an area dictates how much space there is for development and where different types of activity would have originated.

The development of transport is in the main part technology driven. As different technological advances have occurred the development has tended to be focussed on that new area. The earliest forms of transport were primarily concerned with moving goods rather than people. In Europe the first public transport were really the horse drawn omnibus services which were established in the 1840s. These were converted to horse tramways later on in the 1800s. Steam power took over in the 1880s but by the early 1900s tramways had become electrified.

The first passenger railways were constructed in the 19th century as inter-city routes. Britain opened the world's first metro in 1863 from Paddington to Farringdon and the first deep tube tunnel in 1890 from Elephant and Castle to the City of London. The London underground soon developed into a comprehensive metro system. Similarly Paris has developed a comprehensive underground metro system during this century.

It is the cultural tradition that helps to shape the legal and political system of a country. These systems give the basis on which the planning system is formed. Planning systems can be controlled from central government or by local authorities or there can be a complex interaction between the two. The conception of land ownership and development rights arises out of the type of planning system in place.

The economic state of a city also contributes to the pace of its urban development. Here again it depends on the political orientation as to whether the development is regulated or if there is a free market economy. Land use planning tends to be more formally and bureaucratically tied up. Transport planning can vary more with the view of a particular government. Therefore it is more difficult to provide a set picture of how transport planning occurs in each country.

This section will outline the principal planning processes throughout Europe. The impact of closer EU integration will also be discussed.

2.3.2 General European Planning

The growth of power in Europe has implications for planning in European countries. Spatial policy is a national, regional or local responsibility according to the European Commission (1994). The same report argues that it would be beneficial for the European Union if there was greater central intervention in regional and urban policy. In reality some states would not support such intervention.

Whatever control the EU may have over urban planning by controlling finances, urban planning still takes place within a particular national framework. Planning gains its power from the legislation and regulations, which are part of the legal 'apparatus' of a particular country (Newman & Thornley, 1996). The variations in national and legal constitutional structures from country to country can affect different styles of planning systems. Administrative systems can also have a significant impact on planning.

To gain an insight into the different planning systems in Europe it is necessary to look at these two areas:

- European Legal Styles,
- Balance of power between local and central government,

Newman and Thornley (1996) identified different European legal styles:

- The ***British*** legal system which has evolved in the main from English Common Law, a system of case law that has gradually built up decision by decision. There is an emphasis on past experience and precedent. No special status is given to local authorities and they are traditionally seen as the deliverers of services.
- The ***Napoleonic*** system is based on abstract legal norms and greater theoretical debate. A complete system of rules is formed based upon the

codification of abstract principles. There are strong vertical links between the different government levels but the local government is not simply the local agency of central government but contains local representation.

- The ***Germanic*** system was developed later than other European countries primarily because of a lack of central power. An abstract and intellectual approach was used to develop a written Constitution, which is given much importance. The regions have strong decision making powers.

- The ***Scandinavian*** system has a strong relationship between central government and regional government. Central government has its own agency operating at the regional level to implement national policy whilst the local authorities have been reorganised into larger and more efficient units.

Newman and Thornley (1996) also point out that countries tend to conform to their legal and formal arrangements to varying degrees. They suggest that southern countries are likely to be characterised by a greater flexibility in conforming to laws. In Britain and Ireland the powers of local government are defined and highly constrained by central government. French communes[5] on the other hand have strong claims to autonomy even though power does extend down from the centre. Similar differences would be seen between the northern countries of The Netherlands, Belgium and Luxembourg as opposed to the southern countries of Italy, Portugal and Spain.

Some of the planning systems to be found in Europe are described country by country:

In ***Britain*** planning is divided into 3 broad functions:

- Development Control – Local authority receives applications for development and makes a decision taking into account the policy framework and detailed local circumstances.

- Development Plans – Land-use policies are set out for an area (two levels, structure and local), these are not legally binding, and "other material consideration" can over-ride them.

- Central Government Supervision – Enacts legislation and issues Planning Policy Guidelines (PPG) of which there are two types – topic based and area-based. Any development control decision can be appealed to central government.

Central government has much power to influence local policy through its policy guideline documents. The PPG mechanism allows governments to change policies quickly resulting in a lack of a consistent approach over time – these documents could be used as political tools for gaining support approaching election times. This inconsistency and the lack of comprehensive overall planning guidelines results in a lack of coordinated regional and national planning.

The Structure Plan must be in line with policy set out in the government PPGs. This will probably require the planers to refer to a number of topic-based documents and a regional document. The Local Plan in turn must be in line with the Structure Plan. These plans are required to deal with transport planning as well. The traditional approach to transport planning in the UK was to try to cater for the increasing demand for car travel – 'predict and provide'. Planners extrapolated past road traffic growth forward and produced plans to build new road and improve existing ones so as to accommodate the growth. This roads policy reached its peak in the document "Roads for Prosperity" (DoT, 1989) but was abandoned in 1994 with the publication of the "Trunk Roads in England Review" (DoT, 1994). Rosenbaum et al (1998) point out that the traffic forecasts in the two documents had not changed but that the government did not wish to build more roads to solve the problem. This may have been more of a

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[5] Commune: smallest administrative area

monetary consideration rather than a response to research showing the folly in pursuing a policy of extensive road building.

In fact the UK is taking a more sustainable approach to transport policy now. In 1994 a Planning Policy Guidance on Transport was published as PPG 13 (DoE & DoT, 1994) in which the government set out guidance so that the local authorities would carry out their land-use policies and transport programmes in ways that would:

- reduce growth and reliance in use of the private car, and
- encourage more environmentally friendly means of travel.

The guidance goes on to say that transport policies and proposals should be developed through the land-use planning process in such a way that the two processes complement each other.

The ***Irish*** planning system is similar to the British system in that it is based on development control, development plans and central government supervision. One significant difference is that planning permissions, decided on by local authorities, can be appealed to a Planning Appeals Board, which is an independent tribunal. This decision is final and can only be challenged on a point of law. The Irish planning system will be discussed in greater detail in the next chapter.

Until the 1980s the ***French*** system was highly centralised but since then planning power has been shared with local government. There are four levels of government with an interest in planning:

- State – produces national rules and guidelines. It is also largely involved in large infrastructure planning such as extending the TGV and motorway networks.
- Region – can prepare development plans, but few have done so, and according to Newman & Thornley (1996) these regions may be regrouped into larger units.

- Departements – have no specific planning-powers, but have a wide range of functions that impact on urban issues and planning decisions.

- Commune – involved in a 2 tier system of plans:

  (i.) *Schéma Directeur:* non-compulsory intercommunal plan, which is usually produced in conjunction with the state. Usually concerned with general planning objectives and major infrastructure projects.

  (ii.) *Plan d'Occupation des Solutions (POS):* all communes with a population over 50,000 have such a plan, which comprises a strict zoning plan. This non-compulsory plan provides the commune with the power to determine applications to develop and also for some communes, the right to buy key development sites. If no POS is in place then the state assumes planning powers.

Allowing the communes to buy key development sites enables them to decide the type of development for that site. This can be very beneficial in achieving an integrated land-use and public transport approach to planning. In 1982 France brought out legislation called the 'Loi d'Orientation des Transports Interieurs' (Organisation of Land Transport Act) which provides a framework under which a city government or a group of local governments in co-operation may establish a 'Autorite Organisatice' (AO), which is transport organising authority for the conurbation (Denant-Boemont et al, 1999). The AO is required to prepare a traffic plan for the conurbation and make decisions on new transport infrastructure.

The Netherlands can be described as a consensus state where unity is achieved through agreement between government levels (Newman & Thornley, 1996). There are three layers of government, each of which has independent legislative and administrative powers under the overall supervision of the central state. All of the levels can formulate regulations (consistent with a higher level) that are involved in planning. The three layers are:

- National Government – prepares the Physical Planning Act, which is a framework for planning throughout the system. National planning priorities are set out in occasional Reports on Physical Planning.

- Provincial – an elected government which coordinates the actions of the municipalities. Different national government departmental directives are integrated and translated into orders for implementation by the municipalities. A regional plan (Steekplan) which outlines the future development of the province is compiled and is binding on the municipalities. This provides a unified planning approach to the province.

- Municipal – involved in the development of two plans:

  (i.) *Structure Plan (Struktuurplan):* not obligatory and is intended to provide a background for the second plan.

  (ii.) *Bestemminsplan:* legally binding plan.

In ***Germany*** the decision-making structure is decentralised, with the planning system operating at a state (Land) level. The Federal government sets out a framework of regulations to ensure basic consistency. Principal regulations regarding land-use and development control are contained in the Baugesetzbuch, which incorporates the Federal Building Law. All of the Länder are obliged to set up comprehensive plans with regulations for the protection of the environment. There are two types of plans:

(i.) Preparatory land-use plan which is a zoning plan for the whole local authority area and is binding on public authorities but not on the public,

(ii.) 'Bebauungsplan' details the accepted land-use of plots and is legally binding. Public consultation is provided for in the development of this plan.

In ***Switzerland*** the federal state is divided into 3 levels of government, all of which are involved in planning:

- National or Confederation level – sets out the general law on planning aims and principles. It also coordinates the planning at canton level.

- 26 Cantons – produce canton regional plans and formulate Planning and Building Laws. Zoning plan sets out the permitted use of all land and is legally binding.

- > 3,000 communes

The Swiss government has developed a national spatial strategy called "Guidelines for Swiss Spatial Development" which went to parliament in 1995. This provides a framework for the plans of the cantons. One of its principal aims is to improve public transport between cities. New commercial development is to be concentrated on public transport nodes and the peripheral growth of each city will be restricted to prevent congestion.

2.3.3 EU Influence on Planning

It is evident that planning gains its power from the legislation and regulations, which are part of the legal 'apparatus' of a particular country. A number of different legal styles are in existence in Europe and hence this leads to different planning systems. There is a different balance of power between local and central government in each of the countries examined. In addition, the northern European countries would tend to stick more rigidly to their system where as the southern countries would have greater flexibility.

There is a question over how much influence the EU will exert over planning. In some quarters there is expectation that national planning systems will move towards greater uniformity in the future. The European Commission has identified the following trends (CEC, 1994) in spatial planning in Europe:

(i) wider concern with social, economic, transportation and environmental matters,

(ii) market forces are being accounted for,

(iii) streamlining of planning procedures,

(iv) decentralisation of responsibility.

The EU is clear that it wishes to see a greater emphasis on sustainable development. The first trend above could be described as the first steps towards sustainable development policy. According to the Commission planning will become more locally based but with reference to guidelines from above. There will also be steps taken to speed up the planning processes and involve private investment. This gives an indication that the EU sees itself as guiding the strategic direction of policy in the Union whilst still allowing individual states have control over how to implement such policy.

2.4 Study Cities

2.4.1 Basic Statistics

A number of cities have been chosen in which to investigate the relative performance of their public transport systems. These cities are listed in Table 2.3 in descending population order. Most of these cities have LRT systems, whilst some are seriously considering constructing one. This section will concentrate on public transport in general whilst the next sub-section will investigate the individual light rail systems in more detail. The categories used to compare the cities are as follows:

- population,
- modes available,
- ridership of public transport,
- planning context,
- operational context.

Table 2.3 shows that of the cities chosen only three don't have a light rail system. Two of these cities Copenhagen and Dublin are planning a system, while Newcastle in fact has a metro system. Newcastle is the only city with a population of less than 500,000 that has a metro system. All of the cities studied have bus systems.

		Population ('000)	*Metro*	*LRT*	*Bus*
1	London	6,300	✓	✓	✓
2	Paris	2,000	✓	✓	✓
3	Hamburg	1,709	✓	✓	✓
4	Copenhagen	1,700	✓		✓
5	Brussels	1,100	✓	✓	✓
6	Dublin	1,100	■		✓
7	Lille	1,100	✓	✓	✓
8	Koln	1,012	■	✓	✓
9	Rotterdam	888	✓	✓	✓
10	Amsterdam	724	✓	✓	✓
11	Lisbon	610	✓	✓	✓
12	Dusseldorf	571	■	✓	✓
13	The Hague	564	■	✓	✓
14	Bremen	549	■	✓	✓
15	Sheffield	528	■	✓	✓
16	Portland	509		✓	✓
17	Manchester	450	■	✓	✓
18	Newcastle	281	✓		✓
19	Strasbourg	252		✓	✓
20	Utrecht	250		✓	✓
21	Nantes	244		✓	✓
22	Grenoble	150		✓	✓
23	Rouen	105		✓	✓

Table 2.3: City Information (■ means that there is suburban rail rather than a full metro system)

Data for number of passenger journeys on each mode in each city were compiled from Jane's directories (Jane's 1997, 1998 & 2000). It was decided to present this data for 1996 since that was the most recent year that information was available for almost all of the chosen systems. Figure 2.4 shows the number of passenger journeys for each mode per population of that city. The cities are grouped together in regions to aid the discussions in subsequent sections.

The data is scaled by the population so as to allow a comparison of public transport usage to be made between the different size cities. Unfortunately the bus data for English cities is not representative since only information for some operators is available. Data for passenger journeys in the German cities of Bremen, Dusseldorf and Koln was not available in any of Jane's directories.

The key observations from Figure 2.4 are:

- Bus journeys account for the greatest number of journeys per population in the majority of the cities,
- Paris has the greatest usage of public transport per population of the cities being compared,
- In Paris an average person takes 550 metro journeys per year, which is over 100 more journeys than by bus per year.
- Lisbon has the highest number of bus journeys per population per year,

New French LRT systems carry about 100 – 150 journeys per year per head of population.

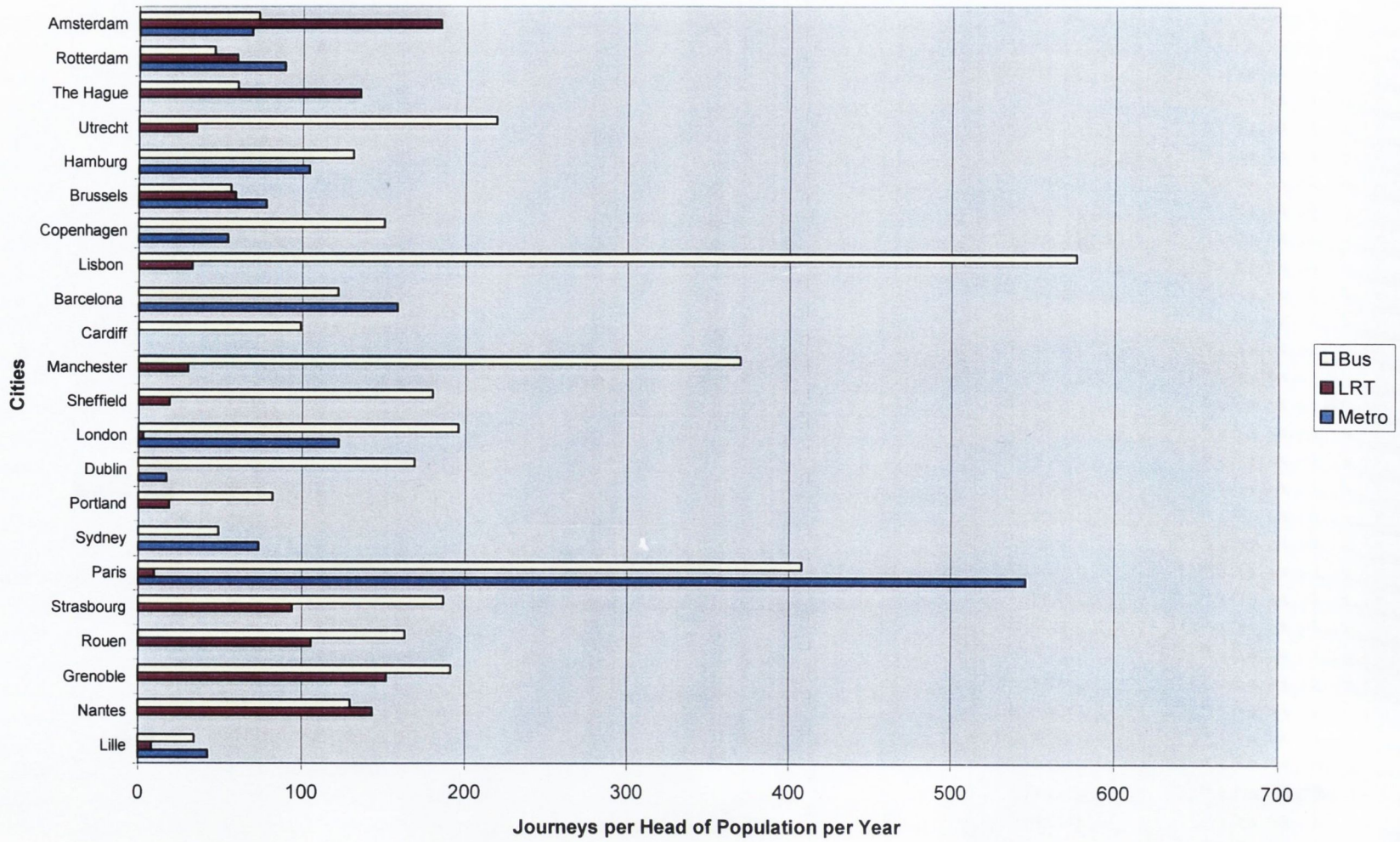

Figure 2.4: Journeys per population.

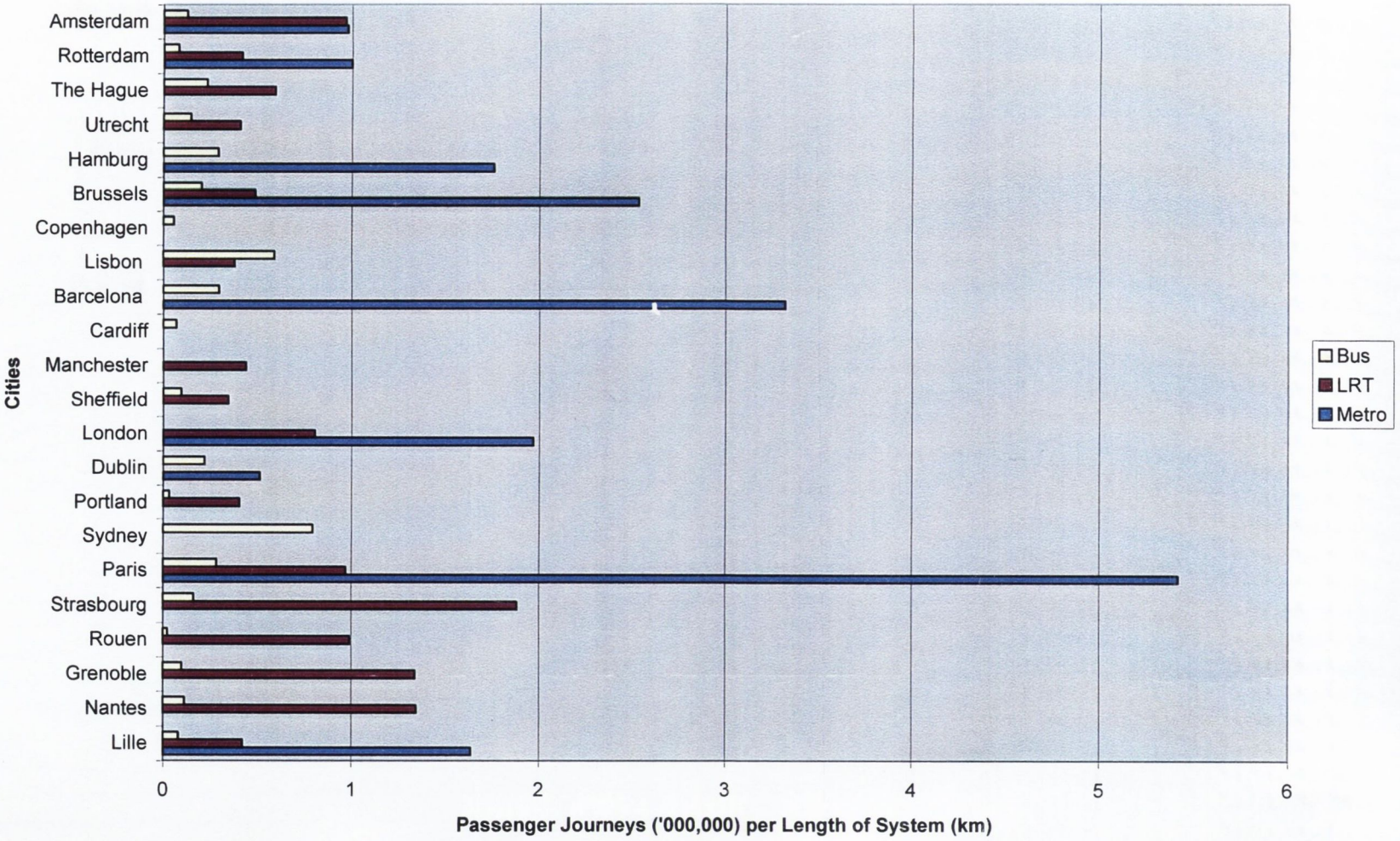

Figure 2.5: Journeys per length of system

Figure 2.4 gives a good indication of the level of use of public transport per person in each city. This graph gives no indication of the performance of the actual public transport network. The network's performance can be measured against the length of its route. A second graph, Figure 2.5, is developed for the study cities which shows the number of passenger journeys per length of system. The following are the key observations from the figures:

- bus systems carry a low numbers of journeys per length of system,
- new French LRT systems shows higher patronage per length of system than older Dutch systems or English systems,
- Paris and Brussels all show good patronage levels for length of metro,
- Dublin, Lisbon, Portland and the English cities of Sheffield and Manchester fail to register over 1 on the scale.

It appears that continental cities carry greater numbers of journeys per system length than English and Irish cities do. This may be a function of the residential and workplace densities of the cities. Intuitively the systems that carry more journeys per system length are more efficient. An efficient use of public transport investment would be considered as a key part of sustainable urban development as discussed earlier in this thesis. The planning mechanisms in each of the cities are examined to see what impact they have on the level of public transport usage.

2.4.2 Co-ordination and Operation of Public Transport

In many of the continental European cities public transport is coordinated by a municipal authority. In some cases such as in Amsterdam, The Hague and Brussels the municipal authority also operates the public transport system whilst in Copenhagen the municipal authority provides supervision for private operators on the tendered routes.

In all of the Dutch cities the municipal authority provides public transport services under a national and financial framework with a subsidy provided from central government based on the number of paid journeys (Jane's, 2000). In contrast STIB (Societe des Transports Intercommunaux de Bruxelles), the Brussels municipal public transport provider, is funded solely by the Brussels regional government.

The German system is similar in that public transport is provided by a municipally owned operator but differs in that a separate body coordinates public transport. These co-ordinating bodies are known as Verkrsverbunde. The organisation is made up of the public transport providers, which would usually include the local public transport operator, DBAG (German mainline railway operator) and possibly a small number of private bus companies.

Copenhagen provides an example of coordinated deregulated public transport system. HT (Hovedstadsomradets Trafikselskab) provides the co-ordination by supervising all public transport services in the region. Its principal roles are the planning and marketing of services as well as the invitation of tenders for services. Competition between operators is based on service quality and costs. HT receives all fare income and pays operating costs to the contractors for the provision of service.

In Dublin bus and suburban rail services are operated by autonomous divisions of the state owned transport company, CIE (Coras Iompar Eireann). CIE was split into the separate autonomous operations for rail, Dublin city buses and provincial and rural bus services in 1987. CIE remains as a holding company with overall responsibility for financial control. There are plans to deregulate public transport in a manner similar to that in Copenhagen. This will be discussed in more detail in the next chapter.

In France public transport is usually provided by a municipal operator owned in part or all by a consortium of local authorities making up the region. In Paris bus, metro, light rail are all operated by a Paris Transport Authority (RATP) under overall control of a board consisting of government and local authority representatives. In Grenoble the bus and light rail system is operated by TAG (Societe d'Economie des Transports en Commun de l'Agglomeration Grenobloise, Semitag) which is a company owned by the

23 local authorities covering the 212.5km^2 city region. A subsidy is paid by the consortium of local authorities and is funded by a 1.75% payroll tax on employers. In Nantes the public transport operator, known as TAN, is a semi-public undertaking controlled (and 65% owned) by a consortium of 21 regional local authorities.

In Lille a private company called Transpole (Transports en Commun de local authority Metropole Lilloise) has responsibility for policy formulation and the financing of the bus, tram and VAL automated metro systems. Similarily in Rouen and Strasbourg, TCAR (Transports en Commun de l'Agglomeration Rouenaise) and CTS (Compagnie des Transports Strasbourgeois) respectively provide the bus and light rail services through holding the concession from their District.

In the UK public transport has been deregulated except for public transport in London. There bus and metro services are the responsibility of LT (London Transport) under overall control of government. Bus and suburban rail services are operated by private companies under a contract whilst the underground remains directly under the control of LT. LT's function is also to plan, provide or procure services to meet the present and future public transport needs of London. Due to a lack of sufficient funding for many years the underground system requires much maintenance and renewal work. The plan is to fund this through PPF projects whilst operation including signalling will remain with the public sector. Responsibility for the bus and metro services will pass to a new transport authority called Transport for London, which will be part of the Greater London Authority headed by the new Mayor.

Outside of London, there are local government bodies responsible for the co-ordination of public transport provision, called passenger transport authorities (PTA). Passenger transport executives (PTE) implement the policies produced by the PTA. In Manchester the Greater Manchester Passenger Transport Authority (GMPTA) has representatives from 10 district councils and is responsible for the public transport policy. The Greater Manchester Passenger Transport Executive (GMPTE) has been instrumental in delivering the light rail "Metrolink" project and in fact owns Metrolink. The exact operating mechanism for Metrolink will be explained in the next subsection.

In Newcastle the bus services are operated by private companies whilst the Metro is operated by the PTE, called Nexus. Before deregulation there was a good level of integration between bus and metro but maintaining such would be seen to be anti-competitive. Any integration has to be promoted on a commercial basis. The PTE, in conjunction with most of the commercial bus operators in the region, has created a integrated ticketing system – something that does not exist in most UK cities since deregulation.

In Sheffield, SYPTE collects a levy for public transport from each of the 12 local authorities represented. Deregulation has resulted in light rail and buses competing directly on parallel routes. The impact this has had on the light rail system will be discussed in the next subsection.

Public transport in Zurich is provided by a municipal body which coordinates and promotes all forms of public transport in the Zurich region. The actual services are provided by 43 operators. There are nearly 1 million public transport daily journeys which Zurich claims gives them the highest use of public transport per head of population in the western world.

Table 2.4 shows the levels of subsidy, for operating costs, provided by state or local government to public transport services in the study cities. The deregulated UK market is immediately evident as is the tiny subsidy of 4% provided in Dublin. The majority of the rest of the cities receive somewhere in the region of 40 – 70% of their operating costs. The Dutch cities of Amsterdam, The Hague and Rotterdam all receive over 60%. The French cities vary with Grenoble receiving the least at 43% up to Rouen at 66%. The German cities all receive subsidies of over 40%.

City	*Subsidy (%)*
Amsterdam	65
Barcelona	35
Bremen	45
Brussels	62
Copenhagen	47
Dublin	4
Dusseldorf	43
Grenoble	43
Hamburg	41
Koln	45
Lille	29
Lisbon	27
London DLR	0
Croydon Tramlink	0
Manchester	0
Nantes	53
Paris	58
Portland	69
Rotterdam	68
Rouen	66
Sheffield	0
Strasbourg	43
Sydney	40
The Hague	66
Utrecht	55

Table 2.4: Subsidys in Study Cities (Source: Jane's 1999).

2.4.3 Transport and Land-use Policy

Throughout continental Europe public transport is kept under close control by the municipal authorities. The municipal authority retains the authority to determine public transport routes as well as the level of service required. Even where a private company operates the service as in Lille, Rouen and Strasbourg they are directly answerable to the municipal authority. This differs totally from the situation outside London in the UK. The PTA has no control over the number of operators providing service on any route and the level of service provided.

The relative change in performance of public transport in the UK compared to Germany and the Netherlands is a clear illustration of the importance of local government having control over public transport. It also provides so many more opportunities to integrate the public transport planning into the rest of the planning process.

Table 2.5 shows that bus patronage declined by 32% in the period 1966 – 1993 in the UK. The Netherlands and Germany show increases in bus patronage for the same time period. This is primarily because they gave public transport the necessary funding and physical space.

	Bus Patronage	*Rail Patronage*
UK	-32%	+3%
Netherlands	+16%	--
Germany	+34%	+34%

Table 2.5: Public transport patronage changes 1966 – 1993 (Source: Edwards & Mackett, 1996).

Table 2.5 shows that the UK managed to register a 3% increase in rail use during the same period. This is very small compared to the German 34% increase for the same period. It was the decline in use of buses that resulted in an increasing need for government subsidy, which stimulated the deregulation of buses in Britain in 1986.

Bus deregulation has made it difficult for a local authority to organise an effective bus service. The services provided may be cost-effective but in the UK it has not been found to halt the decline in use of public transport (EC, 1996).

The outcome of deregulation has actually been to shift the interest of local authorities towards light rail, which they can organise to provide an effective service (Edwards & Mackett, 1996). Unfortunately light rail services may experience direct competition from parallel bus services which is counterproductive for both services. In a corridor where such competition occurs the public transport provision is very inefficient and the allocation of resources are not being used effectively. It also does not assist in the strategic aim of increasing public transport patronage through increasing the proportion of a city serviced by quality public transport.

At the same time Germany has being reinforcing the control that local government has over public transport. The 'Verkehrsverbund' now have the following key responsibilities:

- Co-ordinating the fare structure,
- Co-ordination of timetables and services,
- Strategic planning.

According to Hass-Klau et al. (1998) in recent years the Verkrsverbunde are becoming larger and more complex. Local authorities and the Lander are involved and there is a more regional strategic perspective.

In the Netherlands they are seeking to achieve a compromise between mobility, accessibility and environmental protection (Haq & Bolhuis, 1998). They have found that proximity of employment to public transport nodes is effective in discouraging car use for the journey to work (Owens in Breheny, 1992). In order to achieve higher levels of employment around public transport nodes it is usually necessary to increase the densities of development in such locations. A policy such as this requires close co-ordination between land-use and transport planning.

The Dutch land-use and transport planning provides such a coordinated system. According to Haq and Bohuis (1998) they have gained an international reputation for developing 'coherent policy plans for transport, environment and physical planning'.

The key elements of their policies are:

1. Higher urban densities,
2. Concentration of jobs and facilities at public transport nodes, and
3. Compact urban development.

This is exactly what was prescribed for a more sustainable urban development in section 2.2. This land-use policy is supported with restrictions on car traffic and priority given to public transport and bicycles.

Land-use is split up into 3 distinct types of locations labeled A, B and C as follows:

A-Location: very accessible by public transport, accessibility by motor vehicles is of secondary importance, commuting by car is restricted to 10-20%,

B-Location: reasonably accessible by both car and public transport, and

C-Location: mainly car-oriented locations.

Housing, employment and public facilities are concentrated in A-locations (Haq 1997) and car parking spaces are restricted to 10 per 100 employees in these areas.

Haq (1997) shows that even though overall travel was increasing in the Netherlands, between 1986 and 1993, it was public transport that absorbed the largest increase in passenger kilometres at 41.8% whilst car passenger kilometres only increased by 13.5%. This finding shows the importance of co-ordinating land-use planning with investment in public transport facilities as well as fiscal and regulatory constraints on private vehicles.

In the instances where the municipal authority has control of public transport provision then it should be feasible to plan systems in a complementary manner to the land-use planning of the area. In the case of Brussels STIB is also the overall planning authority. This new administration voted in 1989 to give greater priority to public transport with the following outcomes:

- Improved frequencies
- Completing current metro projects
- Studying further tramway extensions
- Expanding park and ride facilities.

Figures 2.4 and 2.5 were studied to see if any conclusions could be drawn as to the effect that the different co-ordination and operating mechanisms might have on patronage. The key difference would have been between the continental cities and the English deregulated cities. Due to the lack of complete data for the English cities no definite conclusions can be drawn. It is hypothesised though that the continental experience shows that municipally coordinated public transport systems are effective in gaining market share over the private car.

2.4.4 Summary

Throughout continental Europe public transport is kept under close control by the municipal authorities. The municipal authority retains the authority to determine public transport routes as well as the level of service required. Even where a private company operates the service as in Lille, Rouen and Strasbourg they are directly answerable to the municipal authority. This differs totally from the situation outside London in the UK. The PTA has no control over the number of operators providing service on any route and the level of service provided.

The relative change in performance of public transport in the UK compared to Germany and the Netherlands is a clear illustration of the importance of local government having

control over public transport. It also provides so many more opportunities to integrate the public transport planning into the rest of the planning process.

2.5 Light Rail

2.5.1 Introduction

The successful implementation of a new public transport system from conception to realisation is a lengthy and often arduous process. Extensive public consultation is necessary as a new public transport system impacts on many people. Mackett and Edwards (1996) suggest that the planning process for a new public transport system is determined by a set of objectives. These so-called objectives can be broken down into three sections relating to:

(i) obtaining the system,

(ii) to being cost effective, and

(iii) maximising positive system impacts whilst minimising negative system impacts.

The first two sections deal directly with steps that must be completed for successful realisation of the system. The third is to do with system performance and its impact on the area and on the stated transport and economic objectives.

The steps required to achieve these three objectives will vary country by country. Some of the key issues include:

- type of system proposed,
- will the system be run and/or owned by a private operator or the state,
- political will.

The following sub-sections will step through the stages required for successful realisation of a system by drawing on the experience of different countries. Firstly an

investigation of how the idea of a new LRT system is conceived and planned in each country. Then the steps required to gain approval and funding will be outlined. The different operating environments will be discussed drawing on information from section 2.4. The types of complementary measures used will be investigated. Finally the overall performance of the systems will be compared and an attempt will be made to establish which factors contribute to the most successful systems.

2.5.2 Planning

The choice of mode is a fundamental step in the development of any public transport plan. Heavy rail and conventional bus are the two ends of the spectrum in terms of costs and capacity. Many different modes exist between these two cornerstones of urban public transport. Modes are usually classified in terms of their line capacity but this should not be the sole determinant in choosing the mode. Table 2.6 shows the capacity ranges for the different public transport modes.

Mode	*Passengers per Vehicle*	*Headway (mins)*	*Capacity (Pass/hr/direction)*
Bus	90	15 – 2	360 – 2,700
Guided Busway	130	15 – 2	520 – 3,900
Light Rail	235 – 270[6]	5 – 2	2,820 – 8,100
Metro	4 x 250 – 8 x 250	5 – 2	12,000 – 60,000

Table 2.6: Capacity ranges for different public transport modes.

With reference to Table 2.6 it is evident that bus and guided bus ways can be used where expected demand is up to around 3,000 passengers per hour per direction. Light rail can cater for up to 8,100 passengers per hour per direction. This would be standard

[6] 235 is the capacity of the LRV chosen for the Irish LUAS system. This can be expanded to 270 by adding a middle section. This tram is already in use in Montpellier in the south of France.

capacity for European street running systems but in some countries such as the US they run the light rail vehicles coupled together and so the capacity can feasibly be doubled. Metro is the obvious solution where very high demands of up to 60,000 passengers per hour can be expected.

The development of a new public transport system is usually proposed to provide an efficient way for people to travel. The planners will have objectives that they wish their system to achieve. It may be that the aim is to open up access to an area that previously was only readily accessible by private transport. Another aim can be to reduce traffic congestion in a city by providing an attractive alternative to car travel. The two objectives mentioned are transport related but the planners often also have economic and development objectives when designing the system.

The Netherlands never removed its tram systems and as a result there are extensive tram networks in the cities of Amsterdam, Rotterdam and The Hague. These systems have been maintained and in some cases modernised. Utrecht built a completely new light rail line in 1983, which connected a new residential area with the city centre. New lines are also being planned in the 3 other Dutch cities mentioned. Light rail development in Belgium and parts of Germany has followed a similar pattern. Where cities revamp old tram systems and create new LRT systems, based on the old network, there is a danger that they won't correspond to modern travel patterns (Hass-Klau et al., 1998). In some cases where such a policy is followed, with the necessary complementary measures, it may be a conscious decision by the city planners to return to more sustainable travel patterns. This may force people to change either their place of residence or place of work. Such a move imposes costs on such people, which should appear on the negative side of any cost/benefit analysis.

Newly planned LRT lines that are planned to cater for future travel patterns can be more effective in gaining passengers and reducing operating costs. The planning of the new systems in France and the UK has more direct relevance to the planning of light rail in Dublin. They were all developed from scratch since trams had been abandoned in the 1960s. When planning a totally new system a balance needs to be struck between

minimising construction costs by using existing rights of way, and creating new rights of way through developed areas. The use of existing rights of way, especially for the first line of any system, may result in the line being more accepted the public. By routing the system through developed areas there is an immediate catchment population that will potentially use the system but there are associated public consultation problems and land costs.

In France they found that public support grew dramatically between the time the system was being planned and once it was actually up and running. In Genoble only 53% were in favour of the project going ahead, whilst a year after the trams were running 93% approved of the system (Fox, 1994). Similarly in Nantes the support grew from less than 50% before to over 96% two years after opening (Fox, 1994).

According to Hass-Klau et al. (1998) the French government made a decision to promote electrically powered public transport after the Oil Crisis of 1974. Since 1976 grants of up to 50% of the costs of such investments have been available to the local authorities. As a result the local authorities are very instrumental in bringing about light rail schemes. Nantes was the first district to take advantage of these funds for a modern light rail scheme. According to Christine Lasalle (pers comm.) the Mayor in Nantes saw the development of light rail as a 'vision for the city' and was very instrumental in getting the first line built. He in fact lost his post because people were unhappy with the disruption during construction but the new Mayor continued the project and it is now seen as a great success. The first line was built alongside a mainline railway and so was easy to build. The second line replaced a heavily used bus route.

In England Manchester can be shown as a successful system within the deregulated environment. Metrolink consists of the upgrading of two suburban rail lines, Bury and Altrincham, to light rail with an on-street section in the city centre joining G-Mex to Victoria Station via Piccadilly Gardens with a spur to Piccadilly Station.

Croydon came about in a similar manner as 17 km of the 28 km light rail system is constructed on former British Rail lines with an on-street section in the centre of

Croydon. One of the aims of the new Croydon light rail system was to improve east-west public transport links (Modern Railways, 1998). Croydon already had good north-south rail links but the only public transport east-west was bus based. Traffic congestion was causing problems for the areas viability as a shopping and office centre. Segregated light rail was considered to perform better than a bus option at attracting ridership and reducing car travel and congestion. The planners forecast ridership levels with annual totals of 25 million and 20,000 people using the trams during the 3 hour morning peak period (Modern Railways, 1998).

The Docklands Light Railway, DLR, was primarily developed to assist in the regeneration of the London Docklands area. Its history and performance will be discussed later on in this chapter in the context of regeneration.

In America some light rail systems have been built through areas where population densities are very low and car ownership levels are very high. This has resulted in varying levels of success.

2.5.3 Authorisation, Funding and Implementation

Once the type and route of the system has been chosen and plans have been drawn up it is necessary to get approval and secure sufficient funds to proceed. The actual mechanisms for securing authorisation and funds differ for each country so the process is summarised for the countries being studied.

(a) To obtain authorisation:

- UK: involves getting a Ministerial Order under the 1992 Transport and Works Act.

- Ireland: CIE may apply for a Light Rail Order, which gives it power to construct, operate and maintain a light rail way.

- France: the light rail route may be determined as part of the traffic plan prepared by the AO.

- The Netherlands: plan developed by city council and then necessary to obtain approval from Minister of Transport (central government).

- Germany: Verksverbunde has ultimate planning power if in line with Federal policy.

(b) To obtain funding: often requires obtaining money from both public and private sources. The source of public funding differs from country to country as follows:

- UK: Section 56 of the Transport Act 1968 makes provision for grants of up to 50% of the capital costs (Slattery, 1995). The grant can only be paid on the non-user benefits of the system. Any user benefits should be regained through fares paid by the users.

- Ireland: Central government is funding all of initial system in Dublin. EU would have contributed significantly if the system had been on schedule and to their approval. For future extensions private investment from property developers is being sought.

- France: new infrastructure receives a state grant of 30% for capital costs but the main source of public funds is through the *Versement Transport*, which is a payroll tax levied on all employers and reserved for expenditure on public transport (Slattery, 1995).

- The Netherlands: Majority of funds is provided by central government with the remainder from the city council.

- Germany: cost benefit analysis is necessary to apply for the funds from the Federal Government. Funding from Federal Government may be up to 75% of new light rail costs (Hass-Klau et al., 1998).

In addition EU money is available to those states eligible for Cohesion Fund Aid. This can come in the form of grants aid and subsidised loans with low interest rates. It may be possible to fund some of the capital costs through contributions from those who

benefit in the form of increased land values. Small but significant contributions from developers have funded parts of UK systems such as Docklands Light Railway and Manchester Metrolink.

A large proportion of the funding for the Manchester Metrolink was provided in the form of a Section 56 Grant from the government. In the case of Tramlink in Croydon the Government contributed £125 million of the £200 million cost. Unfortunately this was less than had been expected and some of the design specifications had to be changed to reduce costs before construction.

Implementation of the system can be subdivided into two principal parts:

- Workable contractual arrangements between the various interested parties,
- Physical construction work including utilities relocation and integration with existing traffic,

Due to the nature of the work there will be periods of disruption and traffic diversions during the construction of the system. Informing the public is vital to maintain a good image for the system. This was something that the Croydon City Council took very seriously. According to Tumath (pers comm.) extensive public consultation was undertaken throughout the planning stages. During construction information was made readily available on where roads would be closed and what alternative routes would be available. These moves were necessary to counteract criticisms that had been levelled at the development of Sheffield Supertram. It was suggested in media circles that construction of Supertram caused chaos because the utility companies were not centrally coordinated for the re-routing of utilities. This resulted in some roads being continuously closed.

In the UK bids are usually requested to design, build and operate a new system. Engineering consultancies, construction companies and public transport operators come together to form consortia to put together a tender. In the case of the Croydon system a consortium of Amey McAlpine, Bomabardier and Centre West Buses won the project. The consortium was called Tramtrack Croydon Ltd.

2.5.4 Operation

In the Netherlands, like the rest of the public transport system, light rail systems are operated by the municipal transport department, under a national financial framework. Subsidy is provided by the city council who draw a government contribution based on the number of paid journeys. The light rail systems are included in the Dutch integrated ticketing system. The same type of ticket can be used for bus, tram and underground throughout The Netherlands. It is called the 'strippen' card which consists of strips and each is worth a given amount. Any given journey will cost a number of these strips which are validated on entry. The systems are also physically very well integrated with the other modes – metro, bus and suburban rail.

In Germany light rail lines are run by a municipal public transport operator answerable to the Verkrsverbunde. The Verkrsverbunde would set the fare structure and be involved in setting the timetable and services so that they are coordinated with other modes. The strategic network planning would also fall to the Verkrsverbunde

In France the operation of the system or line is given to the single operator of all public transport services in the conurbation. This means that all public transport services are coordinated and there is no competition between public transport modes. It is the operator who determines the bus network and so the operator does not run bus routes parallel to the light rail as this would increase overall operating costs whilst yielding little increase in revenue from fares. In general the ownership of the light rail vehicles and infrastructure remains with the AO which means that if the operators contract was not renewed the operation could easily be transferred to the new company.

Not all French cities have unified fare structures but all of the cities under consideration here do. It falls to the local authorities in a region to take the initiative to work together and unify the fare structures.

In England the ownership of the light rail line usually remains with the passenger transport authority (GMPTE). The Manchester Metrolink light rail system is owned by GMPTE and is now operated under franchise by Altram Ltd. This consortium took

over from Greater Manchester Metro Ltd and comprises of Laing, Ansaldo and the Serco group. Greater Manchester Metro Ltd were the consortium who undertook the development of the original system. When the extension to Eccles was tabled a new bidding competition took place for construction of the new extension and operation of the whole network.

GMPTE implements the strategic planning for the system and has powers for the following extensions: Manchester Airport, Rochdale and Oldham, Ashton-uner-Lyne, Trafford Park and Didsbury. No operating subsidy is provided to the operator.

Similarly the Docklands Light Railway in London (DLR) is operated under a franchise by Docklands Railway Management Ltd. The system is owned by Docklands Light rail Ltd which is responsible for the assets and future planning.

2.5.5 Complementary Measures

For a system to achieve its objectives it must maximise its impact on its surrounding area. Mackett and Edwards (1996) say that for a system to have maximum impact it should:

(a) have high patronage, and

(b) stimulate development.

For a system to have high patronage the level of service must be such that it will attract people from other modes including the car. Unfortunately Edwards and Mackett (1996) point out that there is a suppressed demand for car travel, which usually means that when space becomes available on the road network it is quickly utilised by new users. Higher patronage levels will also be achieved through the attraction of new trip makers, people who would previously not have made that trip by any mode.

It is the case with many public transport systems in the UK that the planners aim for the system to stimulate development. In most cases these aims are not backed up with the

necessary control measures to maximise their effectiveness. It is only in special circumstances like the Docklands light rail that such co-ordination occurs in the UK.

Complementary measures are measures that are not connected directly to the operation of light rail. Hass-Klau et al. (1998) splits complementary measures into two types, 'hard' and 'soft'. The principal 'hard' measures are those that restrain car use. These involve taking city centre road and/or parking space away from the private car and giving it to pedestrians, public transport or cycle facilities. The development of traffic zones or cells usually accompany such reduction in space for the private car. Traffic is only allowed to circulate within a clearly defined zone and so can not travel through a restricted area and out the other side. This means that in any particular area of the city there is only car traffic that actually has business in that area. The combination of these measures results in the balance clearly moving towards public transport, cycling and walking in the city centre.

According to Hass-Klau 'soft' measures include:

- fare structure and integrated ticketing,
- provision of real time information,
- good interchange facilities,
- image of system and facilities,
- park and ride.

Such measures do not force people into a decision to use public transport but instead encourage them in their choice by providing the best quality service available.

Amsterdam conducted a poll of its residents to determine what direction their transport policy should take. 53% supported the option of a 50% reduction in car traffic as opposed to continuing with their current policy (Lemmers, 1995). This gave the planners a mandate to introduce traffic management elements to complement their public transport strategy, which involved extending the public transport network. The

key moves have been to reduce car-parking places, introduce new parking charges and provide better enforcement. This in conjunction with their ABC land-use planning system means that Amsterdam is a good example of sustainable urban planning.

French LRT systems are fully integrated with the rest of the public transport system. Bus services are usually completely reorganised in conjunction with the opening of a new light rail system. In Grenoble the two core LRT routes have replaced the city's busiest bus routes. The other bus routes have been reorganised as feeder routes. Similarly in Nantes the bus routes were reorganised to complement the light rail network. Some road space was lost for cars due to the tram but the city has a very good orbital roadway, which means that there is no through traffic in the city centre.

In Hamburg an extensive system of park and ride sites have been developed. In all there are 84 park and rides sites with 14,950 spaces (Jane's, 2000). Developers who wish to provide inner city parking are required to pay for the construction of an equal number of parking spaces at a suburban park and ride site.

In Portland complementary measures include the intensification of densities along corridors where light rail is being developed. Portland developed its first new light rail line in the 1980s. Further extensions are being developed in conjunction with recommendations to build at higher densities around the light rail stations (Dueker and Bianco, 1998). Around each of its new light rail stations plans have been devised so that only developments that are conducive to rail travel are allowed. The station area plans (TRI-MET, 1996) include the following measures:

- list of auto-oriented uses which are prohibited in station areas,
- set minimum residential and commercial densities,
- create maximum parking limits,
- implement pedestrian connections for easy access to the light rail station.

The first two measures are unusual. The planners enforce the desire to intensify densities near stations by setting minimum densities. This in conjunction with the prohibiting of auto-oriented uses creates the environment where the developers are forced to develop in a manner that is complementary to the use of public transport. Maximum parking limits and good pedestrian connections reinforce this.

2.5.6 Performance

As has been discussed throughout this section there are many factors that make a light rail system successful. There are also many different ways of measuring a systems level of performance. This may also depend on what objectives the planners set out to achieve through its implementation. Fundamental to the success of any public transport system though is that it should carry an efficient number of passengers for its length. Figure 2.6 is derived from Figure 2.5 and shows the number of journeys per length of system. A number of the systems cater for 400,000 journeys per year per km. Systems that perform above this threshold would appear to be using the infrastructure more productively. It is the French cities that show the highest number of journeys per length of system. As has been mentioned previously these systems have been designed in recent years to serve current travel patterns.

Strasbourg has the greatest number of journeys per length of system followed by Nantes, Grenoble and Rouen. Table 2.7 shows that these 4 light rail systems all have a high frequency of service, integrated ticketing and are fully integrated with the bus network. In addition each of the municipal authorities took the opportunity to restrain car use in the city centre and improve pedestrian facilities in conjunction with implementing the new system. Paris and Lille are different because both these cities have metros as well as light rail. In both cases the metro lines serve the areas where demand would be highest resulting in the light rail catering for areas with lower densities and hence lower demand levels.

It appears that no proactive planning took place in any of the French cities to locate certain developments around public transport or to stipulate development density.

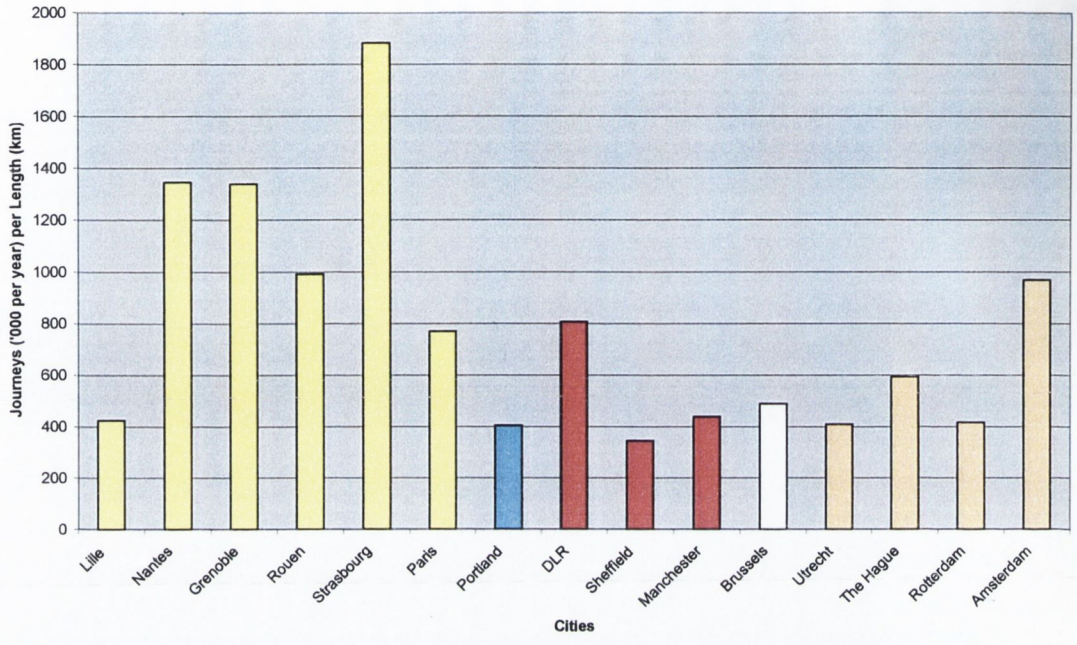

Figure 2.6: Journeys per length

Amsterdam registers a figure of just under 1 million journeys per year per km of system. This is considerably above the 600,000 journeys per year per km for The Hague. Rotterdam and Utrecht are close to the threshold figure of 400,000 journeys per year per km. Public transport is fully integrated throughout the Netherlands both in terms of ticketing and interchange. In Amsterdam it is policy that car use in the city centre should be restricted and that people should be encouraged to use public transport, bicycles or walk. This policy trend is also evident throughout The Netherlands where in many areas cycle paths and pedestrian access are given priority over car access. Planning is also focussed to determine what types of development should take place close to public transport.

It is difficult from Table 2.7 to determine why Amsterdam's light rail system caters for approximately double the number of passengers per km than the other Dutch cities. First hand experience of the city shows the importance of the light rail (or tram) network to the population of Amsterdam for moving around the city. There is an

extensive network of tracks with an even greater number of routes providing easy access to all parts of the city. Amsterdam shows that it is possible to provide public transport services for the complex travel patterns that modern cities generate.

	Frequency	*Ticket*	*Bus*	*P+R*	*Car Rest.*	*Pedestrian priority*	*Integrated Planning*
Lille	3.5	✓	✓				
Nantes	3 – 6	✓	✓	✓	✓	✓	
Grenoble	2	✓	✓		✓	✓	
Rouen	6 – 9	✓	✓	✓	✓	✓	
Strasbourg	3	✓	✓	✓	✓	✓	
Paris	5	✓	✓				
Portland	7 – 10	✓	✓	✓			✓
DLR	4	✓					✓
Croydon		✓					
Sheffield	10			✓		✓	
Manchester	5 – 6			✓		✓	
Brussels	3	✓	✓				✓
Utrecht	5	✓	✓		✓	✓	✓
The Hague	5 – 10	✓	✓		✓	✓	✓
Rotterdam	5 – 8	✓	✓		✓	✓	✓
Amsterdam	5 – 9	✓	✓	✓	✓	✓	✓

Table 2.7: Complementary Measures (Compiled from Jane's 1999 and other sources)

DLR is the only other system to register a figure well above the 400,000 mark at 806,000 journeys per year per km. It again has a high frequency of service and has a

ticketing system that is integrated with the rest of the London public transport network. One of the prime purposes, as will be shown in the next section, for the development of DLR was to stimulate growth in the area. As such it could be said that developments were encouraged in the vicinity of the lines.

The other English systems have results either side of the 400,000 threshold with Manchester slightly outperforming Sheffield. The only complementary policies implemented in Manchester and Sheffield are park and ride and some pedestrianisation as a result of the new infrastructure. A lack of integration with the rest of the public transport network both route wise and ticketing is a serious handicap to the performance of these systems.

Portland with its proactive planning system that encourages higher densities around the stations only registers the threshold 400,000 journeys per year per km. It provides extensive bus connections with the stations, 15 park and ride sites and also cycle parking facilities. Even though it would appear that the public transport has many vital elements in place to gain a high proportion of the commuters there are a number of mitigating factors:

- High levels of car ownership and low fuel prices,
- In general Portland's population density is low even though they aim to increase densities around stations,
- Many established businesses will still have large quantities of parking available to them.

Hass-Klau (et al, 1998) highlights three main ingredients, which have in fact supported by the examination of the study cities, for successful light rail systems:

- complementary measures to restrict car use in city centres,
- ticketing system integrated with the rest of the public transport network,
- high population and employment densities in the light rail corridors.

They must be considered as necessary factors, but it is evident that other local factors may counteract their positive impact.

2.5.7 Summary and Discussion

In the majority of cases examined here the local authority does all the work in bringing about the system but approval must be gained from central government to draw down significant contributions to the costs. In the Netherlands, Germany and France the light rail systems are run, along with the rest of the public transport network, by a municipal public transport operator. This operator may be part of the local authority or may be a company designated to run the public transport. Whichever format is used this single operator can implement a fully integrated public transport network which increases public transport patronage by encouraging multi-trip journeys. This contrasts with the UK where a light rail system is run by a private operator and must compete directly with bus based routes for passengers. It would appear that the European style of operation would be more beneficial for increasing the use of public transport.

For a system to be successful it should have high patronage and assist in stimulating development. To achieve these two objectives it is necessary to implement certain complementary measures. Probably the most stringent measures are those based on restraining car use through taking away city centre road and parking spaces. These are usually accompanied by the development of traffic zones. Other measures discussed were based on achieving a high quality public transport service. This includes issues relating to ticketing, stop design, integration with rest of public transport and provision of park and ride. The final complementary measure that can be utilised involves specifying densities of developments and allowable developments in the vicinity of stops.

The newly designed French systems achieved high levels of trips per length of system. It was shown that each of these cities have certain car restraint measures in place, a high frequency of service, integrated ticketing and are fully integrated with the bus network. In The Netherlands, where many complementary measures are in evidence the light rail systems do not carry as many trips per length as in France. It must be

noted that the Dutch have an extensive public transport network and also that many more shorter trips are made by bike than else where in Europe.

2.6 Redevelopment Areas

2.6.1 Introduction

As shipping methods have changed in recent years the port areas of cities have changed their shape. New areas have been required to accommodate the new larger ships. The advent of containerisation has also meant that the large wharf areas and warehouses are not required any more. This has meant that there are zones of land, often close to city centres, which are either lying derelict or not being used to their full potential.

The London Docklands is one such location where this dereliction occurred. As the Docklands declined through the 1960s and 1970s there was increasing concern about what the closure of the Docks would mean for the social and economic future of the area. Many major planning exercises were carried out but few results were evident until the arrival of the London Docklands Development Corporation LDDC in 1981. The area has now been totally transformed whilst retaining some of its important historical character, notably the large areas of water.

Manchester also experienced similar decline in the Salford Quays area of the city. The City Council purchased much of the former docks from the Manchester Ship Canal Company in 1983. They started a new development around Dock 6 in partnership with the private sector. Due to the success of the initial development the City Council commissioned architects Shepheard, Epstein and Hunter, with their experience of similar schemes in London Docks, to prepare a redevelopment plan for the area. By 1995 the area had 3,500 new jobs.

Amsterdam is redeveloping an old docklands area and also creating seven new islands in the IJmeer (IJ Lake), in a project called IJburg. The purpose of the two projects are to provide more living space for Amsterdammers. There is currently a severe shortage of housing in the Amsterdam area. Access to the Amsterdam region is becoming

increasingly difficult as traffic congestion is getting worse in the morning and evening peaks. According to dRO (dienst Ruimtelijke Ordening[7]) the main lesson to be learnt from this is that building will have to be done closer to the city in areas that are more accessible by public transport (dRO, 2001). Developments further away from the city will mean increased travel and will lead to more traffic congestion.

The study of the planning of redevelopment areas allows the interaction between land-use and transport planning to be closely examined. The change in land-use is usually radically different from what was there before and so requires a very different transportation network. Through co-ordination of the relative location of land-use and transportation a sustainable development led solution is possible. It should be possible to achieve a more sustainable solution then when planning retrofit solutions to developed city areas. In all the cases mentioned above the area is relatively close to the city centre and so a reduction in trip distances is achievable.

In each case the transport infrastructure needs substantial investment and the fact that a docklands area is surrounded and criss-crossed by railway lines and waterways often compounds the access problem. These access problems can be perceived as a potential advantage to the area. Since the transport infrastructure dictates what sort of environment an area will have, the choice is available to limit car use and create a more sustainable redevelopment zone and an improved environment without traffic congestion.

The co-ordination of timing of completion of different areas of the project is very important. Areas should not be fully developed and operational without the public transport system being in place. People make arrangements to travel to a new place of work and it is unrealistic to expect the implementation of a rail system to immediately make them change those arrangements (Walmsley and Perrett, 1991).

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[7] Department of Physical Planning in Amsterdam.

2.6.2 Planning Context

London

In the case of London it was decided that a special body would have to be set up to oversee the redevelopment of the docklands area. The London Docklands Development Corporation (LDDC) was designated the managing body of the Docklands Urban Development Area on 2nd July, 1981, by Michael Hesaltine under provisions of the Local Government Planning and Land Act 1980. The Board of the Corporation was made up of 12 members in all, and was directly responsible to and appointed by the Secretary of State for the Environment. The Government provided the LDDC with unprecedented powers as follows:

(i) Financial resources, provided by the Treasury, through the Department of Environment – initially an amount between £60-70 million per annum,

(ii) Powers as a single development control Planning Authority (in place of the three boroughs), enabling the Corporation to provide a 'one stop service' for investors and developers seeking advice and planning permission (but with no plan making powers, responsibility for which remained with the local authorities),

(iii) Land acquisition powers, with the ability to acquire land quickly from public sector authorities, through special Parliamentary vesting procedures to achieve 'regeneration',

(iv) Powers as an Enterprise Zone Authority responsible for the Isle of Dogs Enterprise Zone, which was designated in April 1982 with a 10 year life.

(v) Finally, powers for marketing and promoting the Docklands area.

An interesting omission from the Corporation's powers was the making of plans. It was decided that such plans would restrict early development. The LDDC set itself the following initial and overall objectives

- To rapidly improve the image of Docklands, not only by undertaking programmes of physical works throughout the area, but also by creating confidence in the continuing improvements to come,

- To use its financial resources primarily as a lever to attract private investment, given that the amount of public money available to the Corporation was small in relation to the size of the task,

- To acquire as much public sector land as resources permitted, in order to undertake the necessary reclamation, servicing and site assembly, followed by remarketing to the private sector wherever such sites were not the subject of suitable active redevelopment plans by their current owners,

- To bring the roads and public transport network up to the standard enjoyed in other parts of London,

- To bring about significant improvements in a choice and quality of housing and community amenities without undertaking such work directly.

Manchester

In Manchester in 1981 zones around the docks in Salford and Trafford were designated Enterprise Zones (EZs) to stimulated redevelopment. This meant that no local rates were required to be paid and there were 100% capital allowances against income and corporation taxes, to last for 10 years until August 1991 (Struthers, pers comm.). Few developments took place in this initial phase and in 1983 Salford City Council purchased much of the former docks from the Manchester Ship Canal Company (Shepeard et al, 1990). By adopting a partnership approach with the private sector the redevelopment of the area was started.

Shepheard, Epstein and Hunter's development strategy of 1985 decided that the land uses would be divided with a third each for housing, employment (light) and leisure (Shepard et al, 1990). The strategy also addresses the following issues:

- location of internal access roads,
- location of pedestrian walkways linking developments and along all quay edges,
- environmental improvement of the area,
- outline development plans for small areas to show scale and orientation in relation to the environment.

The authors believe that the developments should be of urban quality and therefore of fairly high density. No guidelines were given as to what level this density should be.

The M602 was completed in December 1982, which gave the area a direct link into the national motorway system (Law & Grime, 1993). The development strategy did not mention transport beyond recognising the existence of the M602. Parking provision was to be in accordance with the current policy of the City. This would appear to be referring to there being sufficient parking provided by developments rather than any strategic limiting of parking.

The combination of a lack of strategic vision on the location of densities and approach to transportation meant that the area developed primarily in a car orientated manner and so contrary to sustainable policy.

Amsterdam

In 1992 the City Council adopted a policy of reducing the number of cars in the city centre (dRO, 2001). The Council realised though that accessibility was important and so the development of fast and reliable public transport was essential. Coordinated realisation of such a policy is possible because all of the planning powers, both transport and land-use for Amsterdam are held by the City Council. The Amsterdam City Council is broken up into departments that include:

- Department of Physical Planning (DRO),

- Department for Infrastructure Traffic and Transportation (dIVV),
- Municipal Department of Transportation (GVB).

The City of Amsterdam's Department of Physical Planning is an advisory body for all aspects of physical planning and urban development. Its role is to provide a framework within which each of the city's boroughs can create and implement its own policy through the regional plan for the area. Development of transport is the responsibility of the Department for Infrastructure Traffic and Transportation. It is responsible for the accessibility of the city and therefore has responsibility for the *"planning, realisation and management of infrastructure and traffic management systems, and acquisition of the investment subsidies that these require"*. GVB is the public transport operator in Amsterdam and is consulted in the planning stages of any new public transport venture.

Dedicated project teams from dRO are assigned the task of working on large scale development plans such as the Eastern Harbour and IJBurg project. Planning and implementing public transport links to these areas is the responsibility of dIVV.

The Eastern Harbour Area is a dockland redevelopment area, which is available for redevelopment for similar reasons to Manchester and London. The area will provide space for about 8,000 new houses and apartments for a total of 17,000 residents. Housing will be built at a density of 100 units per hectare. The housing will be combined with small-scale industry and commerce as well as shops and schools for the area. By 2005 there will be a light rail system running down the main link between the area and the Central Station.

The IJBurg project is an even larger project in terms of numbers of new residents and new business space. It involves creating islands in the IJmeer and will add an additional 450 hectares of land to the city of Amsterdam. By the year 2010, there will be 18,000 dwellings providing accommodation for approximately 45,000 people. Apart from its residential buildings, IJburg will also have commercial and industrial premises, offices, schools, shops and other facilities. There will be a main centre point on IJburg comprising of shops, restaurants and other public facilities. There will be an

average housing density of 60 dwellings per hectare. Higher density mixed use zones will be located along the public transport routes.

Tram routes linking the areas with the city centre are currently being constructed. A rapid tram service will provide a link to the Central Station and to Amsterdam City Centre. A second connection will be made to the south, to Diemen, initially a fast bus but this will be upgraded to a metro line. The alignments of these public transport routes will be such that they will connect all of the islands so that the whole of IJburg is readily accessible by public transport. It is projected that public transport will account for forty-five percent of total peak-hour traffic, bicycles ten percent and cars fifty percent.

The tram line connecting the city centre to IJburg is called IJtram and a special project team from dIVV is responsible for the planning and construction of the tram line. It will then be handed over to GVB to operate. IJtram will be fully operational by 2002, when 3,000 to 4,000 dwellings will be ready for occupation. The second line will be opened in 2007, when 12,000 dwellings will be ready. In the meantime buses will be used to provide the connections.

2.6.3 Realisation

London

In July 1976 the Docklands Joint Committee recommended a spinal east-west public transport link to knit together the whole of the Docklands. It fell to the LDDC though to address the transport deficit in the area. The transport situation was such that it was isolated from London's transport network and so residents of the area were unable to reach alternative employment as the docks closed down.

The LDDC decided that an automated light railway system was the best solution for the public transport spine in the Docklands. Several routes were investigated but the choice was narrowed down to an east-west route from the edge of the City to the Isle of Dogs and a north-south route from Mile End to the Island. A system of this scale could

never have been justified on transport benefits alone because it was routed though the vacant or underused sites in the Docklands. The LDDC instead had to show that the railway could stimulate different kinds of development including, high employment, high value industries rather than warehousing and distribution.

The east-west route would provide a link between the City and the Docklands and so encourage businesses to consider locating in Docklands whilst the north-south route would link the main residential areas of north-east London into the proposed employment areas of the Isle of Dogs. The two routes would be complementary to each other.

The first public transport service in the area was a bus service called the 'Docklands Clipper' which started in 1984 as a precursor to the Docklands Light Railway (DLR). Its aim was to attract businesses to locate on the Isle of Dogs. This service had a frequency of 15 minutes and a ridership of 10-12,000 people per day by the end of 1984 (NCE, 1998). It was subsidised by the LDDC but owned by London Transport (Squire, pers comm.). This shows the importance attached by the LDDC to improving public transport connections in the area.

The first phase of development was able to start with the stimulus of the site development roads, 'Docklands Clipper' and the promise of the DLR. The start of DLR's construction in 1984 was another significant step and developers and investors began to compete for the development sites. The LDDC (1997) mentions some of the important aspects of the initial development between July 1981 and March 1985 and these include:

- 1.8 million square feet of commercial development,
- Low-density businesses and warehouse units concentrated in the Enterprise Zone,
- 2,500 new homes,
- Low cost homes in Beckton and Surrey Docks initially, followed by

- Conversion of riverside warehouses to loft style apartments.

This DLR system was opened to the public on 31st August 1987. As soon as DLR opened the bus service lost 80% of its patronage in peak hours and the service was discontinued in 1989. Whilst the 2 line DLR system was being constructed a significant move was been made that would change the scale of the Docklands development.

In 1982 the Canary Wharf scheme was first proposed by G. Ware Travelstead. He proposed to build 10 million square feet of offices on Canary Wharf, on top of the DLR (Ridley, pers comm.). This development would have major implications for the public transport requirements of the area. It was decided that the DLR would have to be upgraded and extended with the backers of Canary Wharf paying for an extension to the City at Bank (Squire, pers comm.). In addition it would be necessary to run the trains in two car sets and increase the frequency so that capacity would be increased to 12,000 passengers per hour in each direction.

This upgrade work started as the railway was opening and resulted in a difficult period with major reliability problems for the service. The operation difficulties reached an all time low in summer 1991. This cumulated in the government's decision in April 1992 to transfer the ownership of the DLR to the LDDC. The idea was that the success of the Docklands was so intrinsically bound up with the performance of the DLR, that it had to be controlled and nursed through its problems by the body which had the most interest in its future success. By 1993 the performance of the DLR was significantly better. The DLR is now franchised and the system is run by Docklands Railway Management Limited.

Due to the scale of Canary Wharf DLR would not have had any further capacity to stimulate additional redevelopment of the area. An underground extension was deemed necessary to provide this. The proposal developed into an extension of the Jubilee Line which would link the Docklands with Westminster and the West End. This line was

not high on the then government's list of priorities but Paul Reichman[8] decided to contribute to the development. This extension was opened in December 1999 but it was £1.4bn over budget and 20 months late (NCE, 1999).

An interesting part of the transport schemes has been that they have managed to complete the schemes relatively quickly from the point of conception. A key reason for this is that there was a development authority with necessary powers for land assembly, planning and finance. In spite of this speed of implementation it was impossible for the transport schemes to keep pace with the development on the Isle of Dogs. However in contrast the light rail line through the Royal Docks is in place before any major redevelopment has taken place. The alignment was chosen so that it would link the majority of the residential and development sites together and so maximise its regeneration effects.

Initially the light rail scheme was expected to have to look for traffic and customers and so the initial plans assumed low figures of 1,500 per hour/per direction. The timetable would have provided 8 departures per hour on each of the two legs of the initial railway providing 16 trains per hour on the Isle of Dogs. This looked like being an incredibly good service but was nowhere near enough when the service started 3 years later.

Canary Wharf's population suggested a 250% growth in DLR traffic forecast. Even without Canary Wharf's population in place, the DLR still experienced loadings of 34,000 passengers per day (compared to 22,000 computed from the original Performance Specification hourly flow figures) some two years after opening (Pearce et al., 1994).

By 1997 the working population of Canary Wharf reached 21,000, with 92% of the space let (NCE, 1998). The working population for whole Docklands area in 1997 was 72,000, compared to the 1981 figure of 27,200. The residential population rose from 39,400 in 1981 to 80,000 in 1997.

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[8] G W Travelstead had run out of money and Paul Reichman had taken over the development project

Manchester

Many office developments have taken place in Salford Quays. The plans started out with small-scale offices, which were followed by large-scale schemes. The EZ has also seen many other office developments. In 1993 Law & Grime (1993) calculated that there were 196,000m^2 of office space with a further 233,000m^2 planned. Adding in the office zone in Old Trafford this would give a total of 588,000m^2 of office space compared with 1,300,000m^2 in the city centre. The private sector was involved with the construction of housing in the area. Between 1987 and spring 1991 300 dwellings were completed (Law & Grime, 1993). Hotels, a cinema and three restaurant/bars have also been constructed.

The development was planned as primarily car based and the car parking provision was set at 1 space per 3 employees for financial and professional office developments (Struthers, pers comm.). It was realised that an extension of Metrolink into the area would facilitate the movement of workers, encourage the residential function and link the leisure areas to similar ones in the city centre. According to Peter Black (Black, pers comm.) light rail was preferred to a bus system because of the proven success of Metrolink in the privatised bus environment. He also says that the developers were not forthcoming in financing a pre-Metrolink bus service but did contribute to the Metrolink Extension.

A Bill was deposited in 1987 seeking powers to extend the Metrolink System through Salford Quays. Permission was granted in 1990 under the Greater Manchester (Light Rapid Transit System) Act 1990 (GMPTE, 1996). It was subsequently agreed that the system would be extended on to Eccles from Salford Quays to increase the level of off-peak ridership and counter flows. The Salford Quays section will produce a very peaked flow.

The Salford Quays Extension will result in an increase in the number of trams running through the centre of Manchester from 10/hour to 15/hour in each direction. In contrast to buses, rail and trams systems have an inherent stability as far as routes and stops are concerned. Some of the key office development have taken place around the proposed

route of the line (Black, pers comm.). In fact the Development Strategy Review (Salford City Council, 1988) identified that land to the north of Huron Basin and Erie Basin would be near the new line and proposed that further commercial development should take place there as a result.

The Council has not adjusted the car parking policy to be complementary to the development of public transport in the area. According to Black (pers comm.) this is not possible due to the extensive competition between neighbouring council areas for developments. The Development Strategy Review (Salford City Council, 1988) says that multi-level parking may need to be provided where demand is high.

Amsterdam

As this project is still in its early stages it is hard to say anything on the realisation of the project except that it has the potential to create a sustainable urban environment. The key requirements seem to be in place as follows:

- Eastern Harbour residential density of 100 dwellings per hectare which could give a value of 200 pph,
- Eastern Harbour development is of mixed land-use with small-scale industry and commerce as well as shops and schools for the area,
- Eastern Harbour will be linked to the Central Station with a light rail line,
- IJBurg project will have an average residential density of 100 pph,
- IJBurg project will also be of mixed land-use with commercial and industrial premises, offices, schools, shops, restaurants and other public facilities.
- A number of tram lines are to be built and it is proposed to increase densities around the public transport stations.
- The tram lines will be in earlier in the project development.

2.6.4 Three Redevelopment Areas in Summary

The three examples described here show three very different approaches. In the case of London, public transport investment was considered vital to open up the area for development. Development control was also very limited to try and reduce the barriers to developing the area. As a result with the arrival of Canary Wharf the area has really boomed but due to a lack of control the land-use might not be optimally located relative to the public transport.

Manchester's Salford Quays was developed primarily as a car orientated development. Public transport in the form of Metrolink has only been added at a later stage. The level of parking provision in the area would appear to mitigate against a large transfer to using the new public transport.

Amsterdam on the other hand is approaching the redevelopment of its docks and the development of new islands in an integrated and prescriptive manner. This has the potential to create the most sustainable urban area of the three. The current economic climate is very different compared to when London Docklands and Salford Quays were seeking investment. It would have been difficult for London and Salford to have produced as sustainable plans as Amsterdam in the 1980s.

2.7 Steps Towards a Sustainable Urban Environment

The following objectives were proposed as being necessary for a more sustainable urban environment:

(i) reduction in trip distances,

(ii) reduction in number of trips,

(iii) reduction in car dependency, and

(iv) increased use of environmentally friendly modes of travel.

It was concluded from examining theory and case studies that these objectives can be achieved through the implementation of an integrated strategy of coordinated transport and land-use planning. As a result it is possible to say that coordinated transport and land-use planning is a requisite for improved urban development.

Urban density was considered to be the single most important factor in reducing car use. To increase public transport use and reduce car use it was found that population densities should be greater than 50 pph. These higher density areas should be focussed around rail stations with a quality level of service. In addition it was necessary to concentrate the workplace destinations around central stations.

To reduce trip distances and increase the use of walking and cycling the central area should be of mixed land-use and have good pedestrian routes. It is also suggested that increasing population densities to over 100 pph will be helpful in achieving the four objectives. Complementary transport policies such as a reduction in available parking and road space for the private car will also help to maximise these objectives.

The ability of a city to achieve such objectives is dependent on the planning structures that are in place in its country. It is evident that planning in turn gains its power from the legislation and regulations, which are part of the legal 'apparatus' of that country. One of the key elements of planning is the differing balance of power between local and central government throughout Europe. Another key element is the growing influence of the EU over planning. The EU wishes to see a greater emphasis on sustainable development. It sees itself as guiding the strategic direction of policy whilst still allowing the individual states to control how policy is implemented.

It is apparent that most European countries are starting to embrace sustainability as a strategic goal, but with different levels of success. Another element necessary to achieve the fourth sustainability objective is the provision of quality public transport. The way public transport is controlled differs across Europe. It was shown that across much of continental Europe the municipal authority for a particular area controls public transport. 'Control' means that even if a private operator runs the routes the municipal authority determines what public transport routes should be provided and the level of

service required. This is seen to differ totally to the situation in the UK (apart from London), where the authorities have no control over how many operators provide service on a particular route or of what level of service is provided. It was concluded that the continental model of organising public transport lends itself best to integrated planning and hence sustainability.

The continental style of public transport operation was also considered to be the best for achieving high levels of public transport patronage. The LRT systems on the continent were accompanied by wide ranging complementary measures including car restraint. Land-use measures were found not to be used in any the French cities but were in place in the Dutch cities. An attractive public transport service that was competitive with other modes was considered essential.

Redevelopment areas were examined as they provide a potential environment for the development of a more sustainable urban environment without the usual constraints of changing a developed environment. Three redevelopment areas were compared, two in England and one in Amsterdam. In the first case, in London Docklands, public transport was considered vital to stimulate development but little control was used as to where developments should be located. In the second, Manchester's Salford Quays, the area was redeveloped in a car-orientated manner. Amsterdam though is approaching its development in an integrated and prescriptive manner. As a result Amsterdam has the greatest potential for creating the most sustainable urban environment.

Chapter 3

Development of Dublin

3.1 Introduction

This chapter will review transport and land-use planning in Dublin's recent history. This will focus on the administrative structures and decisions that have given Dublin's its shape. An extensive examination of the DTI process will be included as it had and still has a significant contribution to the shaping of Dublin in the last 7 years.

The extraordinary growth of traffic in Dublin will be discussed. Following on from this the new trip patterns that have occurred due to the location of new developments will be discussed.

A number of new measures and plans have been put in place that will shape Dublin over the next 15 years. These will be examined to put in context the plans for the docklands study area. Finally the Dublin docklands area will be examined to see how the area has developed since its conception.

3.2 Irish Planning System

3.2.1 Introduction

Ireland's planning system is just about to undergo a major change. A new planning bill has just been enacted that, in the words of Mr. Dempsey, Minister for the Environment and Local Government will:

> *"...usher in a planning regime that will promote sustainable development, be strategic in its outlook and be effective and efficient in its operation." (DoE, 25/8/99).*

It is the old system that has shaped Ireland over the past few decades and so it is necessary to look at this system first. This planning system will be discussed with particular reference to Dublin, as this will provide the background for subsequent chapters in this thesis. The new bill and its implications will be discussed in the section relating to the latest plans for Dublin.

3.2.2 Planning 1963 – 1999

The planning system in Ireland was formed around the Local Government (Planning and Development) Act 1963. Many items of planning legislation and regulations have been passed since, which have further developed the system. The various acts are usually referred to collectively as the *Planning and Development Acts* and the regulations as the *Planning and Development Regulations*. It is the Minister for the Environment and Local Government who is responsible for planning legislation.

The greater Dublin area is divided up in to 3 county councils and one county borough corporation. They are as follows:

- Dun Laoghaire/Rathdown County Council,
- Fingal County Council,
- South Dublin County Council,
- Dublin Corporation.

The principal instrument of regulation and control of development are Development Plans. There are certain procedures and guidelines that must be followed by a local authority when preparing a development plan.

- A development plan should set out the authority's policies and objectives for land-use in its area, including the control and promotion of development with regard to particular areas,
- Each Planning Authority must make such a plan and review it every five years,
- The public must be given notice that a draft development plan is being prepared or varied and the draft then has to be displayed for at least three months.

- The public may make submissions during the three-month period and any submissions must be considered before a Plan can be adopted.

- The draft plan should also be sent to various statutory and voluntary bodies so that they will give specialist advice (such as the Environmental Protection Agency (EPA)) and to the adjoining local authorities.

As described here the development plan system results in a prescriptive kind of planning which depends on the private sector to actively propose developments. Development plans must be drawn up in a way, which complements market processes so that proposals are forthcoming from the private sector. The 1963 Act had been conceived so that local authorities could have developed or secured land for development but lack of financial facilities means that this has not happened (MacLaran, 1993).

On the surface the Irish Planning system would appear to be very democratic. Public consultation is a primary part of all the processes. On the other hand the public consultation process is cumbersome and according to MacLaran (1993) results in more of a public relations exercise rather than empowerment of the people.

Development Plan reviews don't usually take place as often as every 5 years due to the length of time the public consultation takes. Dublin has just adopted its 1999 Development Plan with the previous Plan being adopted in 1991. This is an 8-year gap as opposed to the desired 5-year gap.

Planning control lies firstly with the relevant local authority, but this can then be appealed. As mentioned previously Ireland is unique among European countries in that this appeal is to an independent third party planning appeals system – An Bord Pleanála (Planning Appeals Board). It generally takes 2 months for a local authority to decide on an application and after the decision there is a further 1-month for making an appeal to An Bord Pleanála.

The planning authorities are restricted in the way they assess planning permissions and their decision must have regard to:

- the proper planning and development of the area concerned, including the preservation and improvement of amenities,
- the development plan,
- any submissions or observations made on a proposed development.

In addition the authority is required to give reasons for a refusal. Anyone may appeal a planning decision to An Bord Pleanála. The board examines the relevant issues independently and must consider the proper planning and development of the planning authority's area and any submissions or observations received. The board's decision may only be challenged on a point of law.

Certain projects[9] also require an Environmental Impact Statement (EIS) to be submitted with a planning application. This generally is the case when a proposed development may have significant environmental effects.

The Irish planning system is similar to that of Britain in that it is "reactive and discretionary" (DEGW, 2000). This means that it generally lacks a greater strategy and vision for planning. It is also often more flexible to pressure for or against development. The continental plan led system is prescriptive and more proactive. This enables a more long term strategy to be set down with visionary plans.

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[9] Projects needing environmental impact assessment are listed in the First Schedule of the European Communities (Environmental Impact Assessment) Regulations, 1989.

3.3 Transport Planning in Ireland

Figure 3.1 shows diagrammatically how the different bodies with responsibility for transport planning in Ireland interact. Transportation planning in Ireland is divided between two government departments:

- Department of Environment and Local Government, and
- Department of Public Enterprise.

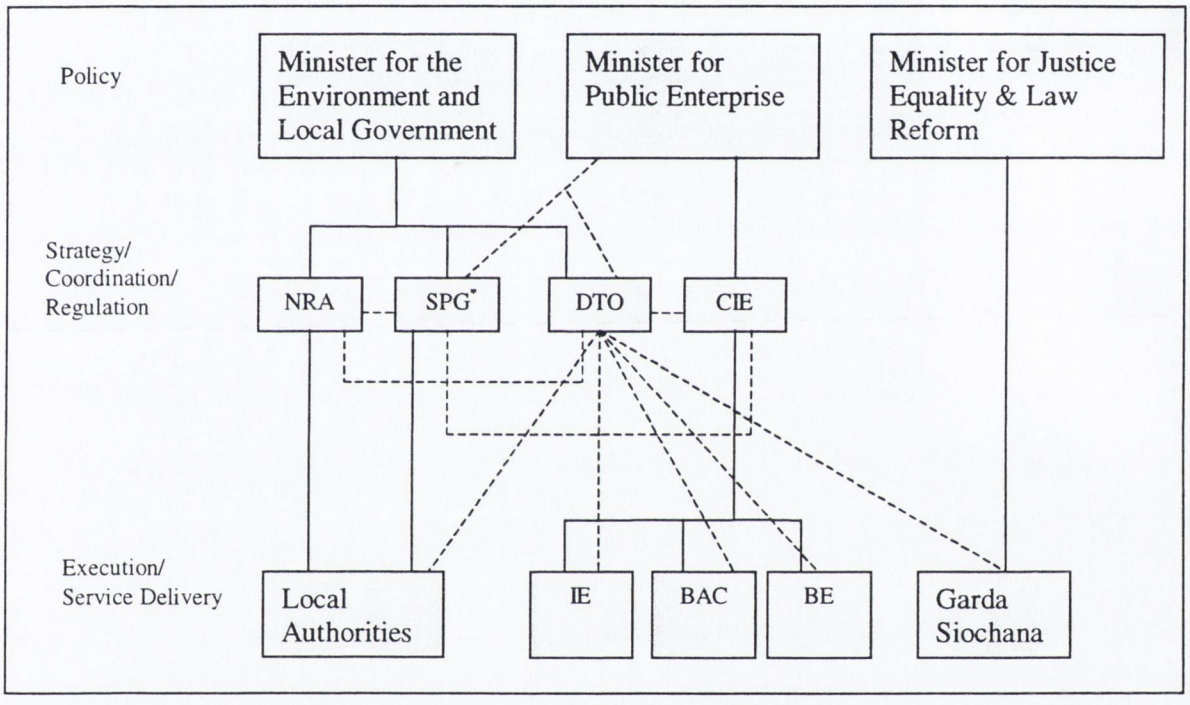

Figure 3.1: Transport Planning in Ireland (Source: DoELG & DPE) (*SPG is the Strategic Planning Guidelines Steering Group)

The Department of Environment and Local Government has responsibility for:

- Roads Infrastructure (through the National Roads Authority (NRA) and Local Authorities), and
- overseeing the activities of the Dublin Transportation Office (DTO).

The NRA was established under the Roads Act, 1993 and began its role on 1 January 1994. The Authority's primary function is to secure the provision of a safe and efficient network of national roads. This involves:

- planning,
- supervision of construction,
- improvement and maintenance of network.

The Authority works closely with local authorities that generally are responsible for specific road maintenance and construction projects. The Local Authorities have sole responsibility for local roads within their administrative boundaries. This involves the maintenance and improvement works on these roads, which must be financed from their own resources, but may be supplemented by State grants.

The DTO was established by ministerial order on 9 November 1995. Its main functions are to:

- coordinate and monitor the implementation of the Dublin Transportation Initiative[10] (DTI) strategy by the relevant agencies involved,
- continuing input to an ongoing strategic planning process,
- review and update strategy at regular intervals.

A Steering Committee (not shown in Figure 3.1), which is appointed by the Minister for the Environment and Local Government, has overall responsibility for the office. Two other committees provide advice and guidance to the Steering Committee:

- Local Authority Committee,

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[10] planning process which produced a set of recommendations for new transport infrastructure and complimentary measures to manage projected growth in the demand of travel over 20 years.

- Consultative Panel.

The business of the Office is managed and controlled by the Director who is assisted by a team of engineers, planners, technicians and administrators who specialise in:

- transportation planning,
- transportation modelling,
- traffic management,
- land-use planning.

The Department of Public Enterprise provides support to the passenger transport industry through it policy making and regulatory functions. It is a shareholder in the commercial state transport companies including Córas Iompair Éireann (CIE). CIE was established under the Transport Act, 1950, and is the main provider of public transport services in the state. The Transport Act, 1958, requires it to provide "reasonable, efficient and economical transport services". A restructuring process took place under the Transport Act, 1986, which required CIE to form a holding company and three major operating companies. The two companies that have particular importance here are:

- Iarnrod Éireann (Irish Rail), and
- Bus Atha Cliath (Dublin Bus).

Irish Rail, amongst other services, provides:

- mainline rail passenger services between Dublin and Belfast, Sligo, Ballina, Westport, Galway, Limerick, Ennis, Tralee, Cork, Waterford and Rosslare Harbour.
- DART (Dublin Area Rapid Transit) service,
- suburban services in the greater Dublin area.

Dublin Bus provides a passenger road service for the city and county of Dublin.

3.4 Development Strategies

Historically many reports have been produced for the planning of the Dublin area. In almost every case though, the whole plan was never realised. Some of the reports did consider the link between land-use and transport whilst others could be described as either independent transport or land-use reports. Due to the fact that the two disciplines are inextricably linked in outcomes it is better to look at all the reports by date rather than by discipline.

Dublin's street pattern developed over many centuries and unlike many other major European cities it was not bombed in World War II. This means that in most cases Dublin, except where building lines have been moved back, retains its narrow streets.

The first attempt to plan the modern city of today could be said to have begun in 1967 when the Myles Wright report (1967) was published. A key element of the report was that four finger-like towns should be developed to the west of the city. These new developments were to be based on a number of small existing settlements and would cater for the predicted growth in population. The four areas were Blanchardstown-Mulhuddart, Palmerstown-Lucan, Clondalkin-Milltown and Tallaght-Saggart. It was envisaged that these would be self-contained entities providing for residential, industrial and service functions.

It was Wright's (1967) view that road-based private transport would be the most important mode of transport in Dublin. In some ways he had a grasp of the land-use transport interaction since he argued that for rail to be successful high density development would be required along the routes. The idea is dismissed as it was "alien to the type of development we recommended for Dublin" (Wright, 1967).

The current shape of Dublin is due in part to this plan. According to MacLaran (1993) the plan was not successful due to the proximity to the city of the development areas. The development areas have created a continuous suburban region stretching out from

the city centre. No organisation was given the role of actively promoting the development of these growth centres. Instead the onus was placed on the private sector and the lack of this success is evident in that Tallaght only got its shopping centre in 1990.

Slattery (1995) says that it was generally accepted that more work was needed to be done on transport plans as detail was sparse in the Myles Wright Report (1967). This resulted in the Dublin Transport Study (DTS) which was published in 1971. The proposals included an outer motorway system with feeder roads. Notably though the report scaled down proposals for city centre road developments and endorsed the upgrading of rail and bus commuter services. Little of this report was realised.

A CIE commissioned study of a rapid rail system, called the Dublin Rapid Transit Study (Vorhees and Associates), was published in 1975. The key points in this report were:

- 71 km rail system, mostly underground, serving 47 stations.
- Development of a city centre terminus west of O'Connell Bridge.
- Extensive feeder bus system to link into the rail system.

A Transport Consultative Commission was set up in 1978 to consider the rail system as proposed by DRTS. In its report (Transport Consultative Commission, 1980) the Commission advocated the prioritisation of improved transport links for Tallaght. This was to take the form of a bus-based service in the short term with complementary features such as bus lanes and parking restrictions.

The package proposed by Vorhees and Associates was dismissed as being too expensive and the only part implemented was the electrification of the Howth/Bray line, DART, which was opened in 1984. The DART is probably the most successful piece of public transport development in recent time and it is interesting to hypothesise on how Dublin might have developed if the whole plan had been implemented. It could be said that the plan comprised two essential elements:

- emphasis on rail providing guaranteed journey times,
- integrated public transport system with 'extensive' feeder buses linking into the rail system.

Due to the position of CIE as sole public transport operator in Dublin it could probably have developed this integrated system. In fact maybe it was in a better position to do it then rather than now. It often appears that Iarnrod Eireann (DART and Arrow services) and Bus Atha Cliath are competing rather than providing an integrated system.

The Eastern Regional Development Organisation (ERDO) was set up in 1969 and was composed of planning staff from the local authorities of Dublin County Borough, County Dublin, Dun Laoghaire and counties Kildare, Meath and Wicklow. The Organisation's objective was to examine population growth in the Eastern Region until 2011. It did this by examining land-use options and paying little attention to the transport effects. The key report (ERDO, 1985) identified the importance of locating additional population near transport facilities – not necessarily public transport though. The report was mainly concerned with the region and does not focus much attention on reinforcing the city centre. There was a conflict in its strategy with those trying to reinforce the city centre and it seems that this body was totally isolated from transport planning.

The latest phase of planning, and from what we owe much of the transport policy currently being discussed, arises out of the Dublin Transportation Initiative (DTI). Its significance is such that it is contained in a subsection of its own.

3.5 DTI

3.5.1 Introduction

The Dublin Transportation Initiative (DTI) was heralded as a new approach to planning in the Greater Dublin area. It began in 1988 when the Minister for the Environment commissioned a review of transport planning. This review included representatives

from the relevant government departments, local authorities and CIE. The second phase of the DTI began in 1992 with the following objectives:

- production of a long-term transportation strategy (to 2011) for the Greater Dublin Area,
- preparation of a medium term Investment & Implementation Programme for the period 1994-1999 drawn from the Recommended Strategy,
- putting in place of a continuous transport planning process.

Extensive public consultation was undertaken during the development of the plans. The Final Report was published in May 1994. The initiative is an integrated one as it deals with all surface transport (road, rail, bus, cycling and walking) as well as issues such as traffic management and enforcement. The approach includes a full assessment of the interaction between transportation and other policies including: land-use, demographics, social and community issues, economic objectives and impacts, and environmental factors.

The report gives direction on some of the critical issues that face any modern urban area. It was decided that:

- the vitality of the city centre should be reinforced by improving public transport, environmental traffic management and commuter parking restraint,
- the car should not be allowed to dominate, but utilised where required,
- an integrated approach to transport and land-use should be pursued.

These are the very issues that are identified as being necessary for a more sustainable urban environment in chapter 2.

The initiative also advised that existing resources should be used more effectively than is the case currently.

- Existing public transport should be upgraded and given greater priority over other traffic,
- SCATS[11] should be extended to cover more of the city,
- Higher density development should be encouraged along strategic public transport corridors in development areas.

These measures were considered necessary to enhance the effect of the report's major infrastructure proposals. The focussing of high-density development along public transport corridors was one of the key conclusions reached in the previous chapter.

The report states that there is a need for a coherent and coordinated overall land-use policy for the entire DTI Study Area, which supports and reinforces the DTI Strategy. Local authorities should take account of the DTI recommendations when next reviewing their development plans. One significant point made is that it was recommended that the C-Ring did not become a focus for retail and leisure developments which would undermine the commercial future of the city centre and be against the proposed strategy.

3.5.2 DTI Methodology

The DTI study team developed eight themes from suggestions made by the relevant transport agencies in the Dublin area. The themes are shown in Figure 3.2. It is evident that these themes are mode based and are not distinctive individual strategies. The purpose of using these themes was so that they would be representative of distinctive policy areas. The DTI team's aim was that evaluation of these themes would allow the strengths and weaknesses of the different mode/policy options, to be assessed. A core strategy would then be constructed by selecting the elements from the themes that performed well.

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[11] traffic light control system

Theme 1:	Do-minimum → small number of road schemes to which the Government was already committed.
Theme 2:	Restraint of Car use → road pricing, parking restraint and complementary management measures.
Theme 3:	Making better use of existing assets → increase use of roads (traffic control improvements) and public transport through the provision of real time information for public transport.
Theme 4:	Incremental road development → completion of major road schemes and some minor road developments
Theme 5:	Extended road development → major road schemes including an eastern bypass of the city and a cross-city East-West tunnel.
Theme 6:	Environmental package → focus on pedestrian, cycle and related measures including traffic calming to give priority to pedestrians and cyclists.
Theme 7:	Enhanced public transport investment → quality bus corridors, light rail system and limited extension to the heavy rail network
Theme 8:	Extended public transport investment → city-wide heavy rail including and underground section, plus an interchange facility in the city centre.

Figure 3.2: DTI theme based approach.

These themes were then tested, using a traffic model, to see how their performances compared. Any transportation planning must be based around a land-use strategy but the DTI process did not involve land-use planning as the body did not have any land-use planning powers. In addition they had no long-term strategic land-use plan to base their transport plans on. Instead it was necessary to identify a range of possible land-use development Scenarios. The authors of the DTI Final Report (SDG, 1994) point out that the land-use scenarios were not to replace any existing land-use plans but were

just hypothesise of how the land-use of Dublin might develop over the projected time period.

The planners identified locations where socio-economic and demographic growth were likely to occur and three land-use scenarios were developed as follows:

- *Scenario A: Urban Concentration* → Household and employment growth concentrated in inner city Dublin and the three Western Towns,
- *Scenario B: Growth Poles* → Household growth concentrated in the Western Towns. Employment growth limited to City Centre, the Western Towns and other outlying areas, and
- *Scenario C: Dispersal* → Household growth outside of city and concentrated along radial roads. Employment growth around motorway C-Ring.

These Scenarios were then developed for low, medium and high growth situations. Table 3.1 shows the population related projections for 2011. This shows that according to the DTI planners 77,000 new households will be required for each of the growth levels because the household occupancy rate will depend on the level of growth.

The performance of the themes was evaluated for the different land use scenarios using a method of multi-criteria analysis based on the model outputs for each theme. The criteria used in the study are shown in Table 3.2. Each theme was assessed by receiving a score for each of the sub-criteria.

	Low	*Medium*	*High*
Population DTI Study Area (millions)	0.99	1.20	1.23
Average Household Size (persons)	2.96	2.86	2.31
Number of New Households	77,000	77,000	77,000

Table 3.1: Scenarios depending on level of growth (based on figures in DTI Final Report (SDG, 1994))

Objective/main criterion	*Measurable sub-criteria*
Employment/regional economy (1)	Encourage economic development (1.1) Consolidate existing industry (1.2) Attract new investment (1.3) Improve physical access (1.4)
Quality of life (2)	Improve comfort and reliability of travel (2.1) Improve traveller security (2.2) Reduce accidents (2.3) Reduce environmental effects of transport (2.4) Improve access to leisure facilities (2.5)
International context (3)	Increase consistency with national/EU plans (3.1) Improve access to markets (3.2) Improve access to Greater Dublin area (3.3) Foster sustainable development (3.4)
Development of city and region (4)	Maintain advantage of city centre (4.1) Provide framework for new town development (4.2) Coherence with plans of surrounding countries (4.3) Help conserve heritage in the area (4.4)
Efficiency in implementation (5)	Maintenance of finance needs at available levels (5.1) Optimise use of existing infrastructure (5.2) Minimise time-scale for implementation (5.3) Capacity for self-enforcement in scheme (5.4) Level of new legislation required (5.5) Contribution to financial health of operators (5.6) Mininmise level of disruption during construction (5.7)

Table 3.2: Criteria used in Multi-criteria analysis

No theme had consistently positive impacts, which in this authors opinion was to be expected since none of the themes are complete strategies. Of particular interest to this work are the following sub-criteria:

- 2.4: Reduce environmental effects of transportation,
- 3.4: Foster sustainable development,
- 4.1: Maintain advantage of city centre.

With reference to Table 3.3 Themes 7 and 8 perform very well in each of these sub-criteria. The rest of the themes have varying results with only theme 3 showing a limited positive impact in each of these key sub-criteria. This shows that themes 7 and 8 would be expected to contribute to sustainable policy as set out in Chapter 2.

The DTI study team then pieced together an interim strategy, using the multi-criteria analysis, but also with reference to their higher level strategic aims. This higher level strategic aim is the main reasons why the direction of theme 5 was rejected. It would have been contrary to the DTI objectives of reducing car dependence and reinforcing the city centre.

Theme	*2.4*	*3.4*	*4.1*
1	– –	– –	– –
2	+ +	+	– –
3	+	+ +	+
4	+	+	N
5	+ +	+	N
6	N	+	N
7	+ +	+ +	+ + +
8	+ +	+ +	+ + +

Table 3.3: Performance of Key Sub-Criteria

The study team was still left with a decision on the mix of public transport modes to be used. A network of quality bus corridors was assumed necessary as the base public transport system. It was necessary to examine the benefits of using LRT and/or DART to complement the bus network. A cost benefit analysis (CBA) was used to compare the relative economic performance of the light rail and heavy rail options. The analysis was conducted on the following two options:

- 3 line light rail network serving, Tallaght, Ballymun and Dundrum, and
- extended heavy rail system serving suburbs to the north, south and east of the city centre as well as a line to Dublin Airport.

Both options were assessed against a baseline bus-only public transport system and the benefit : cost ratio was as follows:

- Heavy rail → 0.40 : 1
- Light rail → 1.76 : 1

This result was instrumental in the decision to include a light rail network in the final strategy rather than an extended heavy rail network.

3.5.3 DTI Strategy

The final report recommends a transportation strategy that contains a package of measures for 2011. As shown in the previous sub-section new public transport links come high up the agenda. The provision of high quality new public transport links to and between the three western towns of Lucan/Clondalkin, Blanchardstown and Tallaght was prioritised. The public transport proposals include:

- a 3 line light rail network serving Tallaght, Dundrum and Ballymun,
- quality bus network complementary to the rail links,
- extend and upgrade DART and suburban rail services,

A rail link to Dublin Airport is also considered important. The importance of an integrated fare structure with transferable ticketing was recognised.

The major road projects proposed include:

- completion of the C-Ring,
- construction of the South-Eastern Motorway,
- construction of the Port Access tunnel.

The Port Access tunnel proposed in the report is a single carriageway tunnel from near the Airport into the port area. It will be tolled for car use to allow it provide its primary

function of providing access for HGVs to the port. Apart from the Port Access Tunnel there will be no significant increase in roadspace on radials within the C-Ring. Park and ride facilities are proposed in the vicinity of the C-Ring to accommodate people travelling from outside the C-Ring and will be linked to quality public transport.

Parking policy is to be changed with an emphasis on deterring long stay parking. Restructuring the charges will do this. There will be a reduction or at minimum no growth in the supply of private non-residential off-street parking spaces. The enforcement of parking laws will become more effective with additional tow-away vehicles and the introduction of wheel clamping. Deliveries should take place outside peak hours and away from road junctions.

The development of environmental traffic cells will continue in order to provide equitable sharing of road space for all. It will also provide a safer and more pleasant environment for pedestrians. In addition a comprehensive cycle network is also proposed.

In reality the DTI transport plans could never provide a long term solution unless a land-use plan was rigorously designed to complement the transport strategy. As shown earlier transport and land-use are inextricably linked and so the planning of each must complement the other. It appears that this has been recognised recently in Ireland with the publication of the Strategic Planning Guidelines.

Unfortunately the DTI plans, though based on valid objectives and providing a more sustainable direction for Dublin's transport, were based on land-use scenarios that had no hold over how Dublin would really develop. Section 3.5 will show how Dublin has actually developed and compare that with the scenarios developed

3.5.4 Modelling of Dublin in DTI

The purpose of this section is to present a summary of the modelling process used in Dublin. Such a summary is necessary as it forms the platform from which this thesis will endeavour to develop a new formulation. In addition it is necessary to put in context the basis for Dublin's recent transport plans.

Model Structure

The DTI transportation model is based on the traditional four stage model structure:

(i) trip generation and attraction,

(ii) trip distribution,

(iii) modal split,

(iv) assignment.

It is a strategic model and utilised primarily as a tool for medium to long term planning. The study area is divided up into 367 zones based on the wards, District Electoral Divisions (DEDs) and surrounding counties. These zones are then aggregated into 58 strategic zones. This enables the land-use and strategic issues to be modelled at this higher level. The transport network of Dublin, including road, bus and rail links, is coded into the model. This combination of 367 zones and network representation allows the actual traffic patterns to be modelled at the finer level.

The software used for the DTI model is SATURN (Simulation and Assignment of Traffic in Urban Road Networks) and SATCHMO (SATURN Travel CHoice MOdel).

Zonal Data

The land-use scenarios were developed for the 58 strategic zone level. These scenarios provide the basic data from which the trip generation data is derived. To develop the trip generation model at a finer level would result in the source data becoming too dis-aggregated and so it also is applied to the 58 strategic zone level.

Growth factors are determined for each strategic zone from the land-use scenarios and demographic data. The model contains much demographic data in the form of dis-aggregated household data. A key variable in the model is whether there a car is available to the trip maker. One of the model's assumptions is that people are living

further away from their employment and so there will be a transfer from cycling and walking to faster modes.

The household data is also complied in terms of the 58 strategic zones. This data is sourced from the Census. Census data is presented at ward level and so is aggregated to the 58 zone level.

Data derived in this way is:

- population (0-14),
- population (15-65),
- population (65+),
- unemployment and employment,
- average occupancy of households,
- cars per household,
- cars per 100 people.

Two separate models were developed to generate the car ownership levels. One predicts the level of driving licence holding whilst the other predicts car ownership levels in individual household types.

The transfer from slow modes due to the future dispersion of residence and employment locations and other factors is also catered for. It is stated in the literature (Steers Davies Gleave, 1995) that there is a trend that trips made by slow modes tend to transfer to mechanical modes over time due to a number of factors including:

- dispersion of population and activities,
- personal safety,
- wider availability of cars.

Census data gives the zonal combined total of journeys to work and education by walk and by cycle throughout the day. The DTI model assumes that the slow mode users share the journey characteristics with bus travellers, as bus is taken to be the next available choice. In effect then there is an assumed migration away from slow modes over time. The slow mode transport characteristics are not factored into the choice process. The modelling of slow modes in such a manner does not allow for the testing of any policies that might increase the use of slow modes.

A base year origin-destination matrix is compiled by surveying the actual trip patterns taking place. In order to collect the relevant detailed information the following origin-destination surveys were undertaken:

- roadside interviews,
- on-board bus interviews,
- rail passenger surveys.

Origin-destination movements were recorded for cars and HGVs during the roadside interviews. A traffic count was undertaken at the roadside interview sites whilst the interviews were being undertaken. This makes it possible to gross the origin-destination information to the relevant totals and produce origin-destination matrices for each site. Checks are made on the validity of the travel patterns recorded and it is also necessary to complete the matrix for unobserved movements from previous data sources. A special program is then used to combine the matrices for each survey site into a complete matrix for the Dublin area.

The bus questionnaires were handed to people as they boarded and people would hand back the completed questionnaire as they alighted. This system enabled the questionnaires to be coded with the actual boarding and alighting stops without the passenger recording this information. The actual questions were compiled so as to provide the DTI with the necessary information and also provide Dublin Bus with sufficient information to undertake their network planning review.

Approximately 25% of the people travelling by bus returned completed surveys. The total number of people travelling on each bus route was extracted from the electronic ticketing machines. This enabled the questionnaire data to be grossed up to the total for each route. The DTI model divides non-car trip makers into two types, those with a car available and those without a car available. Car availability data, was recorded in the questionnaire and as a result an individual matrix is recorded for both types.

Data for a rail matrix was collected in a similar fashion. Survey forms were handed out to people on the suburban rail platforms and they were asked to complete the questionnaire and hand it back at their destination station. This data was grossed up using boarding and alighting counts completed by Iarnrod Eireann close to the time of the survey. A car available and car not available matrix is recorded for rail journeys.

Trip Generation and Attraction

The purpose of this part of the model is to estimate the increase in trips destined to a zone for the forecast year. The trip generation model is applied at the 58 strategic zone level and is consistent with the data collected for the land-use. Two trip generation models were developed one for the peak and one for the off-peak. The peak model concentrates on the journey to work and to school. The growth in work trips is based on the growth in working population in the zone where the working population is defined as the 15-65 age group less the zonal unemployed total. Trips are categorised by whether a car is available or not. Forecasts are produced for trips coming from each zone with reference to the three land-use scenarios described earlier.

A peak trip attraction model is developed with the growth in trips based on the growth in employment in the zone. Since the generation and attraction models are developed separately the trip totals are likely to differ. Trip generation models are considered more reliable due to the growth factors being developed from comprehensive household data. Therefore the trip total calculated from the trip generation model is taken to be the correct one and the trip attraction totals are adjusted to agree with this total.

Production of Future Year Matrices

Two separate growth factors have been determined for each zone, one for the numbers of trips originating in the zone and the other for the number of trips terminating in each zone. An iterative process is required that estimates a trip matrix which satisfies the two sets of growth factors.

The DTI model uses a procedure called the Furness Iteration Technique to generate the future year matrices. This procedure is referred to as a doubly constrained procedure which provides the necessary process to balance the two growth factors. The number of trips in a future year from zone 'i' to zone 'j', T_{ij}, is given by the following formula:

$$T_{ij} = t_{ij}\tau_i\Gamma_j A_i B_j$$

where:

t_{ij} is the base year number of trips,

'τ' & 'Γ' are the growth factors for each zone.

This formula can be simplified by incorporating the growth rates into new variables a_i and b_j:

$$T_{ij} = t_{ij}a_i b_j$$

where:

$a_i = \tau_i A_i$ and $b_j = \Gamma_j B_j$.

The factors ai and b_i must be calculated so that the constraints are satisfied. This is achieved in an iterative process, which is outlined as follows.

1. Set all $b_j = 1.0$ and solve for a_i, in this context, 'solve for a_i' means find the correction factors a_i that satisfy the trip generation constraints.

2. With the latest a_i solve for b_j, e.g. satisfy the trip attraction constraints,

3. Keeping the b_j's fixed, solve for a_i and repeat steps (2) and (3) until the changes are sufficiently small.

This method produces solutions within 3% to 5% of the target values in a few iterations.

Mode Choice

The mode choice part of the model is explained in detail because it is for this process that this thesis formulates a new methodology. It is thus necessary to discuss this procedure in detail so that it can be compared with the new formulation.

The mode choice model used in this process is a hierarchical or nested logit form which is a development of the multi-nomial model. The multi-nomial model is explained in more detail in chapter 4 but for now the specific nested logit form used is dealt with. This version uses the concept of generalised cost as the central factor in the decision process between different modes.

It is assumed that journeys are made for the value (utility) derived from activities performed at their destination. To undertake a journey the trip maker incurs costs in terms of time and expense. The concept of generalised cost is a means of measuring this cost by combining a weighted combination of the various time and money costs. Generalised cost can be measured in either time or monetary units.

The DTI generalised cost includes the following variables: in-vehicle travel time (IVT), walk time (WK), waiting time for public transport (WT), excess time (EX) for finding parking, fares (FARE) and vehicle operating costs (VOC), parking charges (PK), and mode specific penalty.

$$GC_{car} = a_1IVT + a_2WK + a_3EX + a_4VOC + a_5PK + a_6$$

$$GC_{public\ transport} = a^1{}_1IVT + a^1{}_2WK + a^1{}_3WT + a^1{}_4FARE + a^1{}_6$$

The parameters a_1 to a_6 act as both weights and conversion factors to express generalised costs in common units. The DTI modellers converted the generalised cost

into time units. This conversion hinges on the monetary value placed on the value of time. The interpretation used was that the perceived value of waiting and walking times are twice the value of in-vehicle times. This means that a_1 is given the value of unity and a_2 and a_3 are each given the value of 2. Parameters a_4 and a_5 both convert the monetary costs into time units.

As stated already the mode choice model used is of hierarchical or nested logit form. For trip makers with a car available the first choice available is between car and public transport. The proportion of trip makers choosing each is given by:

$$P_{car} = \frac{e^{-\beta GC_{car}}}{e^{-\beta GC_{car}} + e^{-\beta GC_{pt}}}$$

$$P_{pt} = 1 - P_{car}$$

In this formulation β acts as a dispersion parameter representing the sensitivity of mode choices to changes in the generalised cost (GC) by each mode. The next step in the process is to separate the public transport users between bus and rail. Two separate β parameters are required, one for the car available public transport trip makers and one for the car not available public transport trip makers. The formulas for the decision between bus and rail are:

$$P_{bus} = \frac{e^{-\beta GC_{bus}}}{e^{-\beta GC_{bus}} + e^{-\beta GC_{rail}}}$$

$$P_{rail} = 1 - P_{bus}$$

It is necessary to formulate a generalised cost of public transport for the higher nest choice. In the DTI model the generalised cost of public transport is compiled as a combination of bus and rail costs. The formulation is the log-sum average of the respective modes costs:

$$GC_{pt} = -\frac{1}{\beta} Ln\left(e^{-\beta GC_{rail}} + e^{-\beta GC_{bus}}\right)$$

Assignment

In central urban areas, where the roads are short with many junctions under congestion, it is the junctions that are critical in causing the delays. In the DTI model, SATURN interacts with the junction delays so as to give realistic assignment values. The first step is to load a trip matrix onto the network and obtain an estimate of the flows. The assignment model used can perform either Wardrop's or Stochastic User Equilibrium assignment. The second part of this process requires a simulation mode, which represents the movement of groups of vehicles over the network and how these vehicles interact with the junction delays.

The SATCHMO package performs the public transport assignment. It incorporates the key aspects of public transport travel as follows: cost, in vehicle time, transfer time, walk time and wait time. Passengers are assumed to choose the best route in terms of generalised costs. When all of the public transport and car trip makers have been assigned onto routes and travel times and costs calculated these may be significantly different from those used in the mode split models. An equilibration process is used to achieve the correct balance between the estimated generalised costs and those actually produced after assignment. This equilibration ensures that a model achieves a balance between transport supply and demand in each part of the network

3.5.5 Discussion

The principal points drawn out during the discussion of the DTI strategy are:

- aims of DTO are in line with sustainable urban strategy,
- principal weakness of DTI is that it was not coordinated with a land-use strategy,
- main formulation of mode choice in the Dublin model is focused on car, rail and bus whilst cycling and walking are catered for separately,

- the coding of cycling and walking does not cater for the possibility of growth in "slow modes" due to increasing densities and mixed land-use planning,

3.6 Implementation of DTI Strategy

The Dublin Transportation Office was set up to coordinate the implementation of the DTI strategy. There has been considerable slippage in the implementation of the DTI Strategy. In fact many of the infrastructure projects were originally to be finished by 1999. Some of these delays may be attributable to the fact that the DTO has limited powers and implementation of each project is really up to the relevant agency. The division of responsibility for implementing DTI is as follows:

- Traffic policy → Director of Traffic's Department in Dublin Corporation,
- Light rail → Light Rail Office, which is part of the CIE group of companies,
- Strategic road schemes → coordinated by the NRA through the respective county council.

Traffic Policy includes:

- Traffic management: traffic cells, traffic light control,
- Implementation of QBCs with associated traffic management,
- Parking policy including enforcement.

A number of traffic cells have been introduced in residential areas in and around the city centre. More recently a series of turns have been banned except for public transport. The purpose of these turns has been to route traffic away from the city centre that has no purpose there. This enables greater priority to be given to public transport and pedestrians.

On-street parking charges have been changed to encourage short-stay parking. The city has been divided into five parking zones with the highest rate of £1.50 per hour charged in the most central area (IT, 2/2/01). New and extended enforcement measures have also been introduced. Illegal parking is more rigorously enforced than in the past with the introduction of wheel clamping and an increased level of towing of illegally parked vehicles. Clamping was first introduced in Dublin in the summer of 1998. Dublin Corporation report that as a result there are fewer illegally parked cars and that revenue from parking metres has increased dramatically (IT, 13/3/99).

A number of QBCs have been implemented successfully with notable increases in passenger volumes. All 10 proposed QBCs were to have been completed by 1999 but only 4 were completed by 1999. 5 new QBCs opened in the first few months of 2001. The DTO reports that bus passenger numbers have increased by 44% on the Malahide route and by 196% on the Stillorgan route (IT, 2/3/2001). Bus journey times have also been improved.

Many of the delays to the QBCs can be attributed to the unforeseen levels of public protest at the major changes required. The LUAS light rail scheme has also been delayed considerably as Table 3.4 shows. The LUAS delays can be attributed to the extensive public consultation required but also due to a change of national government during which there were long periods of indecision relating to this project.

Scheme	*Estimate of Latest Finish Date (SDG, 1994)*	*Current Estimate of Finish Date (DTO, 1998)*
Tallaght/Connolly	1999	2002
Sandyford/St. Stephens Green	1999	2003
St. Stephens Green/Ballymun	2001	Post 2003

Table 3.4: LRT Finishing Dates

Other delays include:

- DART extension to Greystones and Malahide, had an expected finish date of 1999, but has only just opened with a limited timetable since the end of 2000,

- Dublin Port Tunnel, Southern Cross and South Eastern Motorways have been held up significantly by appeal processes,

- Little progress on park and ride, and integrated ticketing.

On a more positive note over 125 km of two-way cycle track had been built by September 2000 with 2,300 new cycle parking spaces provided (DTO, 2000a).

3.7 Growth of Dublin in the context of DTI

3.7.1 Introduction

The level of traffic growth in Dublin since DTI has been unprecedented. This has compounded the problem of delays in implementing parts of the strategy. The traffic growth has occurred due to the economic growth that has occurred in Dublin since the DTI strategy was published in 1995. Whether you focus on the GDA[12] or the DTI area it is apparent that the figures far exceed those projected. Table 3.5 shows that the DTI projected 49% growth in GDP by 2001 and 42% was achieved by 1996 with the GDA achieving 79% by 1999.

According to DEGW (2000) This growth can be contributed to two significant factors:

- strong pattern of inward investment fuelled by government policy such as the tax incentives in the IFSC,

- EU structural funds which allowed extensive road building.

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[12] Greater Dublin Area

DTI Area	*1991 Base*	*2001 Forecast*	*1996 Base*	*1999 Forecast*	*1999 Actual*	*2016 Forecast*
GDP Growth DTI	Base	49%	42%	70%		
GDP Growth GDA	Base		42%		79%	260%
Pop (m.) DTI	1.14	1.18	1.18	1.19		
Pop (m.) GDA	1.35		1.41		1.46	1.75
Hhlds ('000) DTI	343	378	379	393		
Hhlds ('000) GDA	402		446		521	675
Unemployment DTI	16%	17%	12%	11.6%		
Unemployment GDA	16%		12%		6%	5%
Car ownership per 1000 pop DTI	248	288	300	350		
Car ownership per 1000 pop GDA	247		292		342	480

Table 3.5: Factors Effecting Transport Demand (based on DTO 1998 & DTO 2000)

This growth has resulted in a substantial increase in the number of people living and working in the Dublin region. According to DEGW (2000) 700 people move to Dublin every week, this influx of people includes returning emigrants and young Europeans. Table 3.5 shows that the DTI population forecast for 2001 was reached in 1996. The GDA population figure for 1999 shows that the region's population is still increasing dramatically. In addition unemployment levels have reduced, with the most significant drop being between 12% in 1996 and 6% in 1999 in the GDA. This has meant that there is a very much greater demand for peak period travel. As shown in this thesis already the new travel patterns generated will have been a function of a number of factors including:

- Relative location of place of residence and work,
- Transport modes available for trip,
- Car and car parking availability,

- Relative travel time characteristics between modes.

To investigate the first two factors in terms of Dublin it is necessary to see how Dublin's shape has developed in conjunction with new improved transport facilities. Firstly though the relative location of residence and work will be investigated to see how it has changed over time. Then the transport demand in the city will be investigated.

3.7.2 Relative Location of Residence and Work

The growth has led to a boom in the construction of office space in the Greater Dublin Area. Figure 3.3 shows how the quantity of office space completed each year has risen dramatically since 1996. Estimates (Lyster pers comm.) for 2001 and 2002 show that over 300,000 sq. m. of office space will be completed in each of these years. The location of the new office developments in the late '90s has had a significant impact on the travel patterns. The projected office completions for 2001 and 2002 will in turn further impact the travel patterns. It is debatable whether such a high level of office completions will be maintained over the next 10 years. The signs are that the economy is slowing down which would result in a reduced requirement for new office space.

It is the location of office space in the last 10 years that has been a large factor in creating the current travel patterns in Dublin. The next set of figures show where the office developments have been located during the past 10 years. Figure 3.4 shows the locations of office completions in 1990. Of the 75,000 sq. m. developed the majority was located in the city centre or surrounding areas with only small developments taking place elsewhere. The western section of the motorway opened 12th March 1990 and as a result did not yet make any impact on locational decisions for developments.

In 1991 the quantity of office space completed was 117,287 sq. m. (HOK, 1992), which was a large increase on 1990 but the locational pattern was very similar. The only different location was that just over 12,000 sq. m. of space was completed in Sandyford.

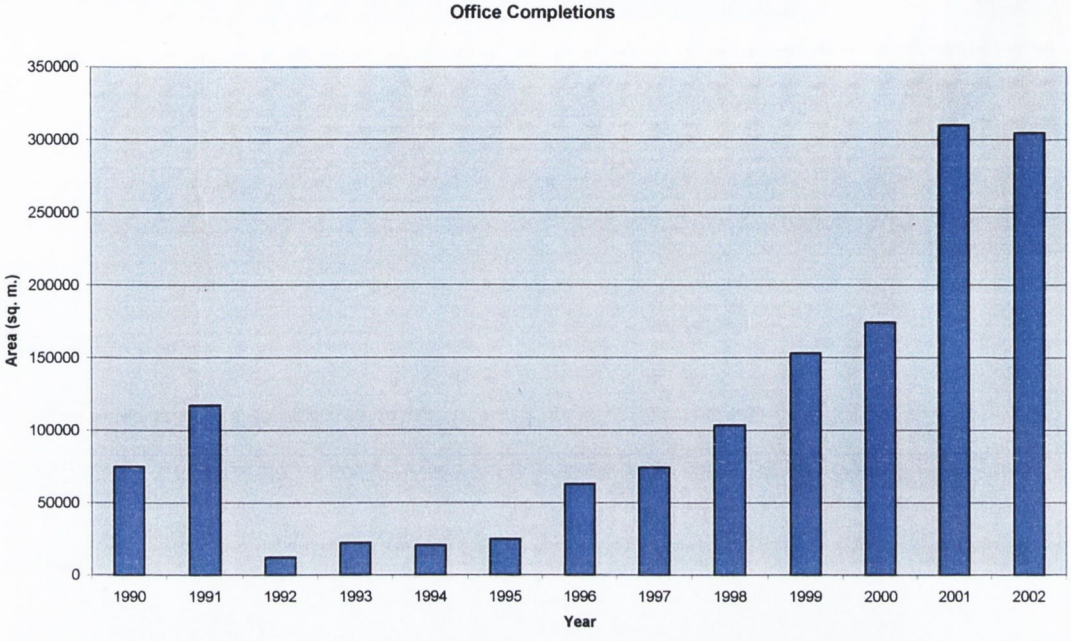

Figure 3.3: Office Completions (Source: HOK, 1991 – 2000 and Lyster pers comm.)

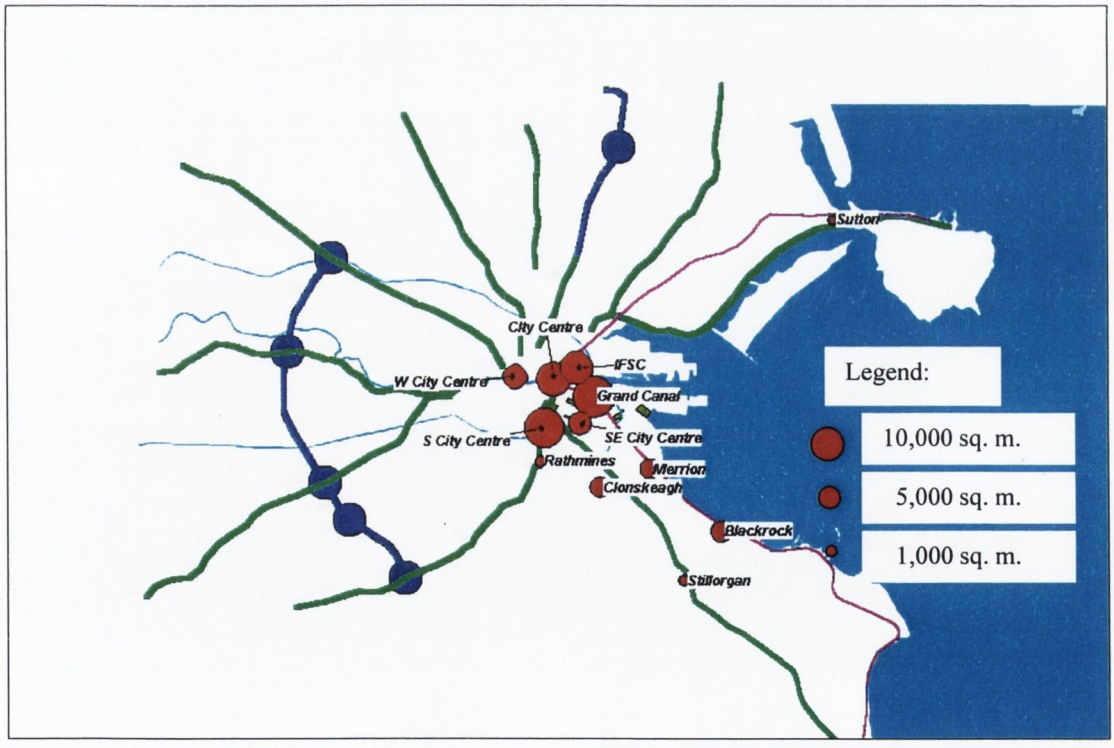

Figure 3.4: Dublin Office Completions 1990 (Source: HOK, 1991)

The economy then went into decline and only small quantities of office space were completed during the next four years:

- 1992 → 12,135 sq. m. (HOK, 1993)
- 1993 → 22,408 sq. m. (HOK, 1994)
- 1994 → 20,570 sq. m. (HOK, 1995)
- 1995 → 24,851 sq. m. (HOK, 1996)

Figure 3.5 shows the locations of these developments over the four years. The city centre absorbed 57% of new office space being developed, with some smaller developments in the areas peripheral to the centre. It is evident that over the four years various small developments took place throughout the southern suburbs of Clonskeagh, Dundrum, Blackrock and Stillorgan. The significant new location during this time period was Tallaght with almost 17,000 sq. m. competed. The M50 corridor accounted for 28% of the new office completions.

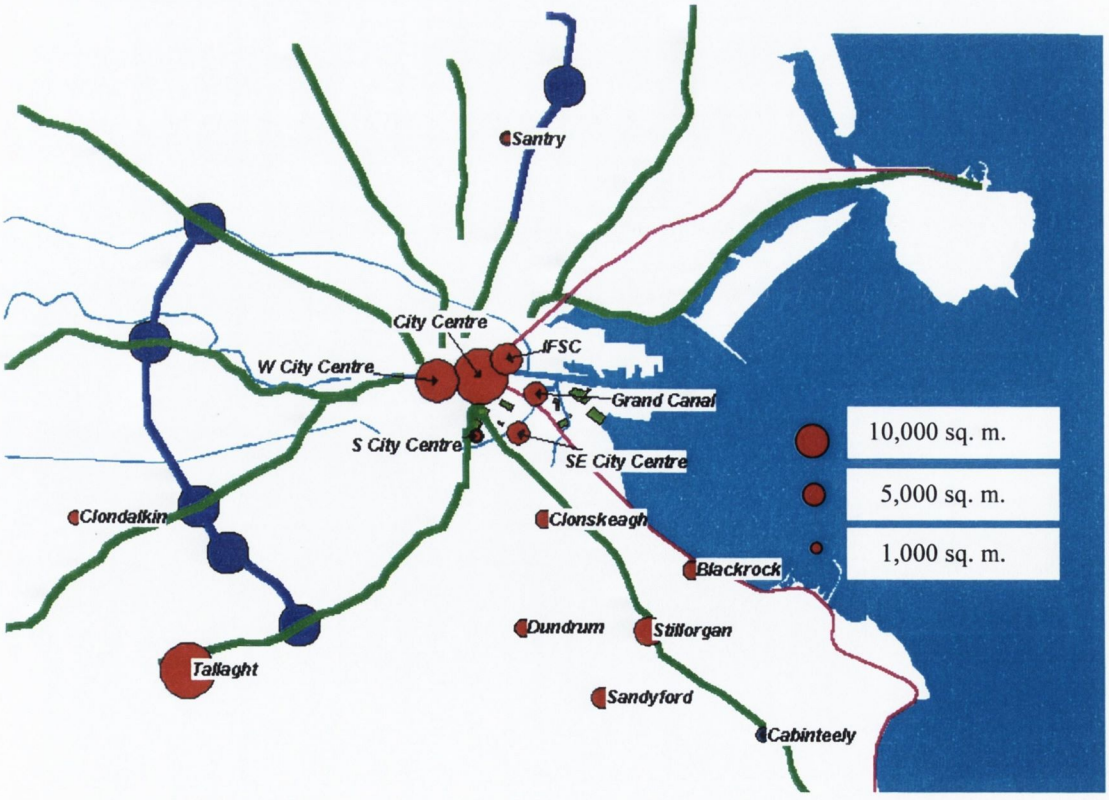

Figure 3.5: Dublin Office Completions 1992 – 1995 (Source: HOK, 1993 – 1996)

In 1995 the northern section of the M50 C-ring motorway opened. This opened up the M50 corridor for development as it provided the vital connection to the Airport and road north to Belfast. 1996 also brought about an increase in office space being completed as Figure 3.3 showed. Referring back to Figure 3.3 it is evident that this growth continued on through the following years up to and including 2000. Figure 3.6 shows the locations of these completions. The city centre and its immediate peripheral areas again accommodate a large quantity of the new space. In fact the city centre locations and the docklands accommodated over 280,000 sq. m. of new office space during these five years. This is 48% of the total completed during the same period. The motorway corridor accounted for just under 40% of the office space.

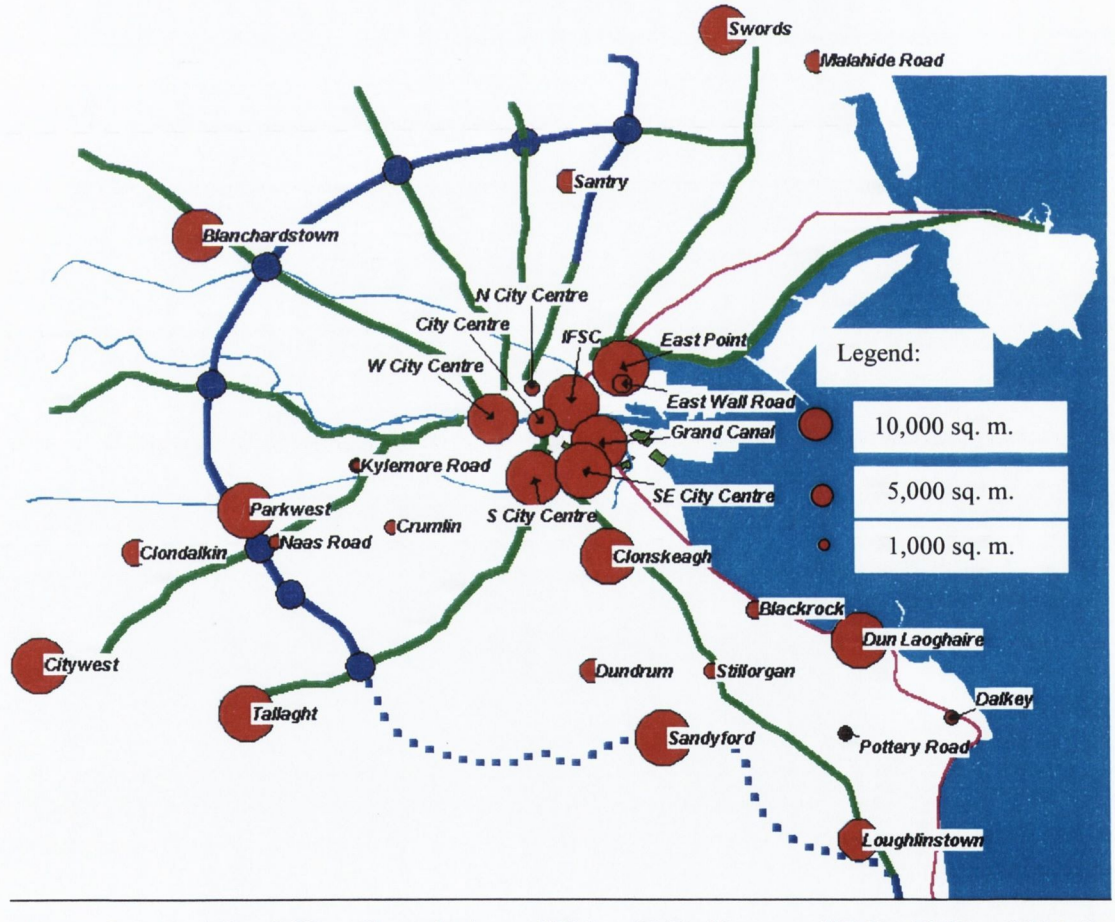

Figure 3.6: Dublin Office Completions 1996 – 2000 (Source: HOK, 1997 – 2000 & Lyster pers comm.)

The completion of this quantity of office space in the motorway corridor means that these locations have become important trip attractors during the morning peak period. The development of large shopping complexes such as Blanchardstown, Liffey Valley and The Square at the principal M50 interchanges has resulted in additional traffic being attracted to these peripheral areas. Due to their location and proximity to the motorway the principal means of access is the private car. This will have resulted in an increase in the proportion of people travelling by private car during the morning peak period.

The location of population has also changed considerably over time. Figure 3.7 shows a decline in population between 1981 and 1996 in the Dublin County Borough whilst the three surrounding county areas of Dun Laoghaire-Rathdown, South Dublin and Fingal all show an increasing population. The only reversal of this trend is in the southern half of the Dublin Corportation area where there was a slight increase in population between 1991 and 1996. With the increase in apartment developments in areas surrounding the city centre it is possible that the 2001 census may show an increase in population in central area.

The principal point from Figure 3.7 is that whilst there has been an overall increase in population in the Dublin area there has also been a shift of population from the central area to the suburbs. Planning has ensured that Dublin remains a predominantly low-rise city. This low density of development in the central area has tended to push the wave of development outwards into surrounding areas. The rising price of land in central locations has also encouraged developers to look else where. With rising car ownership locations that would once have been considered inaccessible to the majority are now accessible by car.

The Dublin Corporation area has a density of 45 pph (excluding The Phoenix Park from the area of Dublin Corporation), which is less than a city such as Copenhagen which has 54 pph (DEGW, 2000). As shown earlier in this thesis densities of over 50 pph are necessary to assist in creating a more sustainable environment.

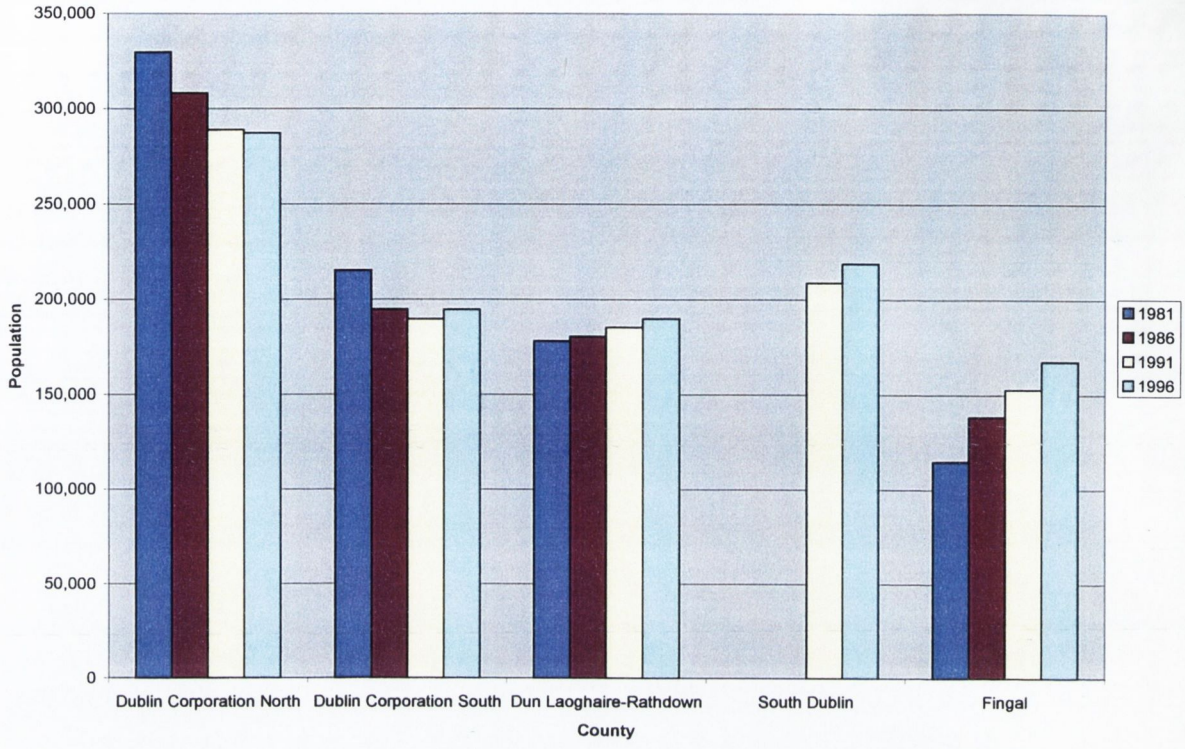

Figure 3.7: Population Changes in the Dublin area 1981 – 1996.

3.7.3 Transport Demand

The trip demand levels show a dramatic increase compared to the forecasts in DTI. Table 3.6 shows that according to the DTO the peak hour demand in 1997 was 234,000 which is significantly more than the original DTI Final Report 2001 forecast of 206,000. In fact the DTO (2000a) revised this 1997 figure upwards to 250,000 in their latest publication. Unfortunately it is the private car that has absorbed the majority of the increase in trip demand. In 1991 the private car accounted for 64% of peak hour trips, but this had increased to 72% of peak hour trips by 1997 (DTO, 2000a). This has resulted in greater congestion and increased journey times.

		Person Trips	Growth since 1991
DTI in 1995	1991 Base	172,000	
	2001 Forecast	206,000	20%
DTO in 1999	1996 Base	227,000	32%
	1997	234,000	36%
	1999 Forecast	240,000	40%
DTO in 2000	1997 Base	250,000	45%
	1999	283,000	65%
	2016 Forecast	488,000	184%

Table 3.6: Transport Peak Demand – Total trips by all modes (Source: DTO 1998 & DTO 2000)

As discussed earlier one of the key objectives of the DTI Strategy was that there would be a significant shift away from the use of the car in favour of public transport and alternative modes. The enormous growth in trips and the numerous delays in implementing the strategy have led to their being a significant transport deficit. This is defined by the DTO as any increase in person-trips over that forecast by DTI.

In its extreme definition it could be described as the lack of available public transport trip slots for travelling into Dublin. The inevitable result of this is that people are forced to either travel by car or relocate either their home or place of employment. Travelling by car increases the congestion and adds to the level of external costs imposed by car users. Relocating a home or place of employment imposes costs on the individual. It is essential that the established and new residential areas are provided with quality public transport to reinforce the city centre and maintain travel patterns that can be served by public transport in a more sustainable manner.

Table 3.6 shows that the DTO now predict that peak hour demand will reach 488,000 trips by 2016. They also predict that the patterns of travel are changing significantly. Their 1997 survey shows that:

- The city centre and south-east city centre continue to be popular destinations,
- Large increase in morning peak hour trip destinations to the Clondalkin/Tallaght area between 1991 and 1997,
- Dublin Airport and Sandyford are also important destinations,
- Extensive two-way trip demand between the western towns of Tallaght, Clondalkin, Blanchardstown and Dublin Airport and its environs.

The high levels of transport demand and the connections to new developments have finally become apparent to the county council planners in the Dublin area. The Irish Times reported (IT, 2/11/00) that Dun Laoghaire Rathdown County Council planners have made a number of developments in the Sandyford to Carrickmines area dependent on the extension of LUAS to Carrickmines.

Car ownership levels have being increasing very quickly over the last number of years. Table 3.5 showed that in the DTI Final Report (DTI 1994) the car ownership figure was forecast for 2001 to be 288 cars per 1,000 persons in Dublin from a 1991 base of 248 cars per 1,000 persons. This 2001 forecast was easily surpassed by 1996 with 300 cars per 1,000 persons (DTO, 1998). The forecast for 1999 was 350 cars per 1,000 of population. It is evident that Ireland, and especially Dublin is moving towards the EU average of 450 cars per 1,000 of population. In fact Table 3.5 showed that the DTO expect the figure to have reached 480 cars per 1,000 of population.

This estimate was published during 2000 when Ireland was heading for a record year in terms of numbers of new cars sold. New car registrations are 27% less for the first 6 months of 2001 than 2000 (IT, 4/7/01). The figures show that 2001 is still 3% ahead of 1999. As with the future level of office completions, the state of the economy will determine how fast the country moves towards or past the EU average.

3.7.4 Increased Car Use in Summary

There are a number of reasons for this increase in car use and change in trip patterns including:

- delays in implementing recommended public transport infrastructure,
- lack of coordinated land-use plan resulting in:
  - locating of large quantity of new office developments around the M50,
  - population shift away from the city centre into the suburbs and beyond,
  - large shopping developments located near principal M50 interchanges.
- large increase in car ownership levels.

3.8 Dublin's Future

3.8.1 Introduction

The planning of land-use and transport is going through a period of change. The first step was the adoption of the new Planning Bill which embraces the sustainable ideals for planning. The publication of the Strategic Guidelines was also a key step in providing a coordinated residential settlement plan for the GDA. This provided a starting point for the latest transportation plans published by the DTO. The new Planning Bill, the Strategic Guidelines and the DTO transportation plans will all be discussed to see how they comply with sustainable urban planning.

The implications of deregulation and the establishment of a Greater Dublin Authority will also be discussed.

3.8.2 Planning 1999 –

The new Planning Bill will revise and consolidate in one Act all nine Planning and Development Acts enacted since 1963 and introduces a sustainable development philosophy to the Irish planning system. The system of development plans will still remain at the core of the planning system but with some changes.

- Local authority development plans will now have a six-year term.
- The plan should set out "an overall strategy for the proper planning and sustainable development of the area" (LGA, 1999).
- The plan must address the matter of necessary infrastructure including transport, energy and communication facilities.
- The Bill sets out a hierarchical system of plans, shown in Figure 3.8, all of which will now have statutory recognition.
- The development plan being at the centre of this hierarchy is subservient to the Regional Plan whilst it sets out the background for any Local Area Plans.

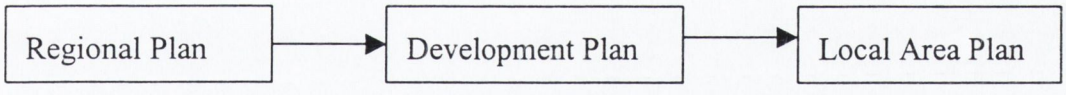

Figure 3.8: Plan Hierarchy

Regional plans have the following characteristics:

- are to be developed for a period of time not less than 12 years,
- to provide for a strategic planning framework,
- the principles of proper planning and sustainable development must be adhered to when preparing the plan.

- the plan should address the following issues:
  - projected population trends,
  - settlement and housing strategies,
  - economic and employment trends,
  - location of industrial and commercial development,
  - transportation.

There are many more issues that the plan must include but these are the ones that have a direct impact on this work. The recognition of regional guidelines will create better cohesion of development plans.

The increased status of local area plans will allow a better link between development plans and individual development proposals. Local plans can be prepared for any area and local authorities can co-operate in devising plans for an area that lies across the boundary of two local authority areas. All of the plans must also contain information on the likely significant effects on the environment of implementing the plan.

The schedules at the end of the Bill (LGA, 1999) set out the objectives that may be indicated in a development plan. A separate section is included for 'Infrastructure and Transport' which shows the powers that a development plan can have over transportation provision:

- Reservation of land for transport networks,
- Facilitating the provision of sustainable integrated transport, public transport and road traffic systems and promoting the development of local transport plans,
- Securing the greater convenience and safety of users of the transport network and of pedestrians and cyclists,

- Establishment of public rights of way, and extinguishment of public and private rights of way,

- Providing for the management and control of traffic, including the provision and control of parking areas.

The inclusion of transport planning in the Bill provides a basic mechanism for the coordinated planning of transport and land-use planning.

Considering the case of Dublin the individual local authorities will be bound to consider the regional plan when reviewing their development plan. This will ensure that the plans are complimentary to each other. In addition to regional plans a national spatial planning strategy is being prepared in the context of the national development plan and to which any regional guidelines and development plans will have to have regard.

It appears that the Bill has put in place the mechanisms for a cohesive planning system, which should allow for consistent planning decisions. All plans must have reference to the fact that development is to be according to 'proper planning and sustainable development'.

The EU's influence on the requirement for 'sustainable development' can be clearly seen in this new planning Bill. An emphasis is placed on the issue of sustainability and allows for vertical integration between the different levels of authority.

3.8.3 Future development of Dublin

The Strategic Guidelines were commissioned to set out how the greater Dublin area should develop in terms of land-use. It was prepared for a group of public bodies including: Dublin Corporation, Dun Laoghaire-Rathdown County Council, Fingal County Council, Kildare County Council, Meath County Council, South Dublin County Council, Wicklow County Council, and the Department of the Environment and Local Government, in conjunction with Dublin Regional Authority, Mid-East Regional Authority by a consortium of consultants comprising: Brady Shipman Martin (Planning

Consultants), Kirk McClure Morton (Consulting Engineers), Fitzpatrick Associates (Economic Consultants), and Colin Buchanan and Partners (Transportation Consultants).

As set out in the new planning bill each councils development plans must take heed of the plan above in the hierarchy. In addition the DTO must take heed of the guidelines.

The SPG have attempted to forecast the level of population growth in the Dublin region through till 2011. The forecasts are based on the following recorded levels for 1996:

- Population: 1,405,671,
- Households: 446,251.

The forecasts are derived from estimates of the economic growth of the area and estimates of the amount of in-migration to the country. Population figures are developed for 4 different scenarios. The 4 scenarios are:

- Scenario 1: natural growth only,
- Scenario 2: 1 + low levels of in-migration,
- Scenario 3: 1 + medium levels of in-migration, and
- Scenario 4: 1 + high levels of in-migration.

Table 3.7 shows the forecast population and household figures for the 4 scenarios. Brady and Shipman (1999), in Scenario 1, predict that with only 'natural growth' the population of the Greater Dublin Area will increase by 10% to 1,545,000 in 2011. With high levels of in-migration this figure could reach 1,650,000 in 2011. They point out that levels of in-migration are very volatile and are closely related to economic circumstances. This high figure of 1,650,000 may not be achieved by 2011 but it is assumed that it will be reached soon after.

	Population ('000)			*Growth*	*Households ('000)*			*Growth*
	2001	*2006*	*2011*	*'01 – '11*	*2001*	*2006*	*2011*	*'01 – '11*
Scenario 1	1,463	1,511	1,545	10%	491	544	604	35%
Scenario 2	1,471	1,530	1,578	12%	495	554	622	39%
Scenario 3	1,481	1,552	1,611	15%	501	566	640	43%
Scenario 4	1,491	1,575	1,650	17%	507	579	661	48%

Table 3.7: Population and Household Predictions (Source: Brady Shipman Martin et al., 1999)

The required household figures are based on a prediction that the household size will continue to fall and will be approximately 2.5 persons per house by 2011. This prediction follows on from recent trends in Dublin towards smaller average family size. The trend is mirrored in all developed countries and when coupled with the increasing population numbers gives rise to a large demand for housing. Table 3.7 shows that with Scenario 1 there would be a 35% increase in housing to 604,000 households in 2011. Scenario 4 would require 661,000 households.

The Strategic Guidelines principal purpose is to designate areas where new additional population should be placed in the Greater Dublin Area. According to the authors the aim is to achieve a better balance between public and private transport by consolidating growth into a limited number of locations. The guidelines propose the following:

- Consolidation of growth in the Metropolitan Area, allowing it to accommodate a greater population than at present,
- Concentration of growth, in the hinterland, into major 'development centres', located on existing or future transportation corridors, and separated from each other and the Metropolitan Area by green belts.

Figure 3.9 shows the red line enclosing the Metropolitan area and then also shows the actual locations of the outlying growth centres. The primary growth centres of Drogheda, Balbriggan and Naas are located around rail links to Dublin and it is proposed to reopen the Navan railway line to allow Navan become a primary growth centre. Wicklow town is also proposed as a primary growth centre. Some other areas are also proposed as secondary growth centres such as Athy.

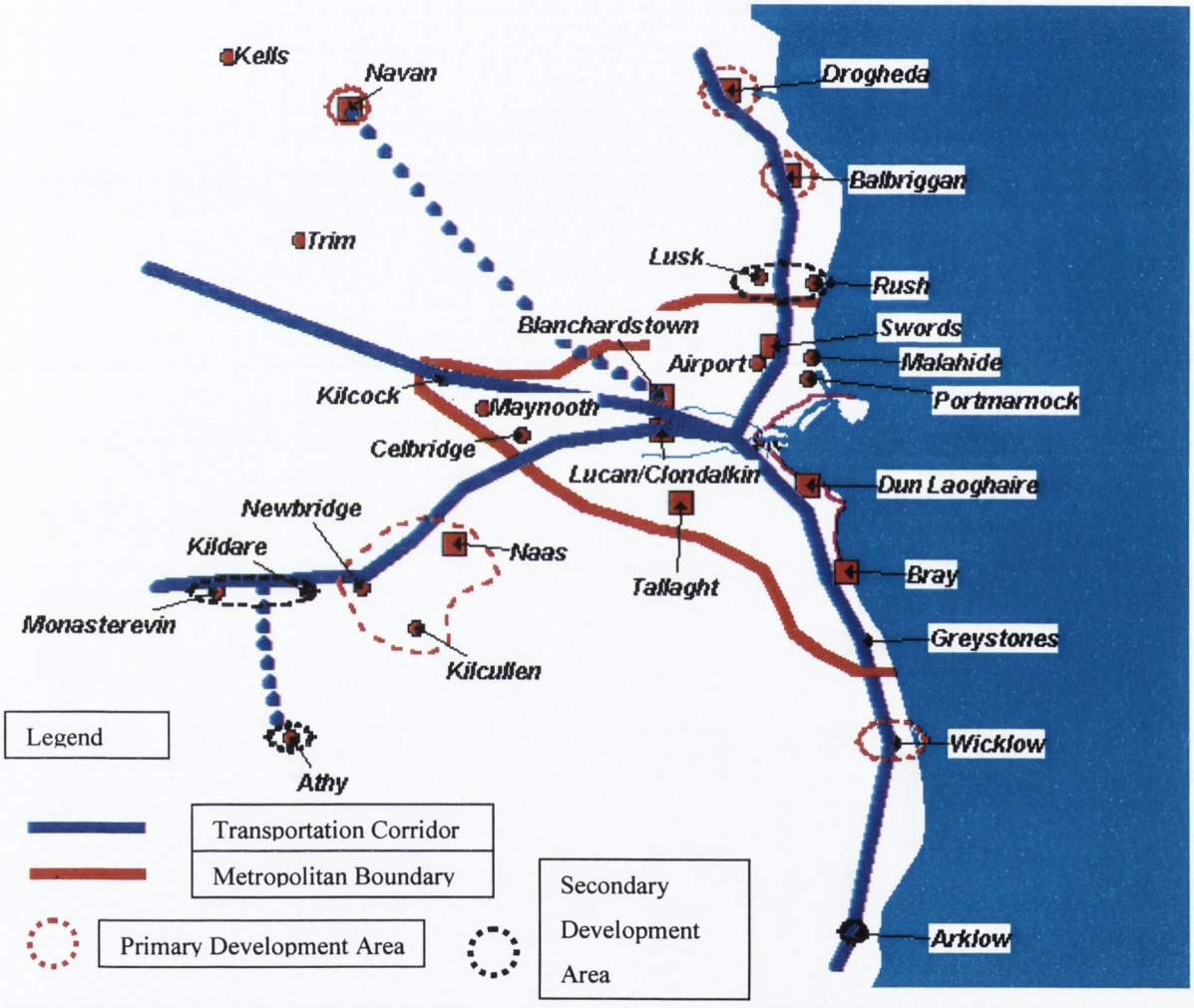

Figure 3.9: Future Development Centres (Based on map in Brady Shipman Martin et al., 1999)

Wicklow County Council plans to designate Ashford, Kilcoole, Newtownmountkennedy and Rathnew for major population growth (IT, 4/12/00). As shown in Figure 3.9 only Wicklow is proposed as a major growth centre. The new

Planning and Development Act described earlier allows the Minister for the Environment to overturn development plans if it is decided that they breach Strategic Planning Guidelines (IT, 11/1/01b). There are concerns that the development plans for Wicklow, Meath and Kildare are providing housing for commuters to Dublin. This is not considered sustainable and according to the Irish Times the plans are opposed by the DTO and in the case of Wicklow, senior planners within the Wicklow County Council.

Table 3.8 shows how Brady, Shipman & Martin (1999) recommend the distribution of population throughout the metropolitan area. It is evident that the largest segment of population, over 40% of the increase in the metropolitan area, is to be located in the southern part of Fingal. Over 60,000 people in over 40,000 houses is a large increase and will increase the density of population considerably. Supporting public transport will be required to allow such development take place in sustainable fashion.

	Population		*Households*	
	1996	*2011*	*1996*	*2011*
Dublin CB	481,854	502,000	173,085	211,000
Dun Laoghaire-Rathdown	189,999	200,000	61,469	82,000
Fingal (South)	136,702	200,000	38,894	80,000
Kildare (North-East)	40,281	46,000	11,668	17,500
South Dublin	218,728	248,000	61,809	100,000
Wicklow (North-East)	41,647	52,000	12,654	20,500
Total Metropolitan Area	1,109,211	1,248,000	359,579	511,000

Table 3.8: Distribution of future population within the metropolitan area.

20,000 additional people are expected to live in the Dublin Corporation Borough in almost 38,000 new housing units. This appears to factor in the lower occupancy rate of city centre apartments compared to suburban houses.

Dublin Corporation Borough has a density of 42 pph (well below the European average). Up to approximately 50-60 pph there are significant reduction in energy use to be achieved as concluded earlier in this thesis. The level of intensification proposed in the strategic guidelines would only raise the density to 44 pph. According to DEGW (2000) Dublin could achieve the 50-60 pph with a relatively modest increase of built space volume coupled with the introduction of an integrated networked public transport system.

As shown earlier Ireland's planning system in general is not proactive – IFSC and Smithfield being examples where the government intervened. This means that even though development plans may specify land-uses and densities for specific areas it may not be possible to get these passed through the planning appeals process. DEGW (2000) in their report on Dublin building heights suggested that key sites should be proactively developed by jointly preparing development briefs for landowners so as to achieve the required intensification necessary.

Brady Shipman Martin (1999) estimate that the numbers employed in the GDA will increase to approximately 770,000 by 2010. This would be almost a 40% increase on the 558,400 at work in 1997. Interestingly the Strategic Guidelines do not advise on the location of employment generators. This is still the sole responsibility of the local authorities which of course means that the locational decisions are driven by economic forces. Lyster (pers comm.) provides estimations for office completions in 2001 and 2002. He estimates that there will be over 300,000 sq. m. of new office space in 2001 and a similar quantity in 2002. Figure 3.10 shows the locations of these new offices, which shows that a significant quantity of office space is located in and around the motorway corridor. In fact over 50% of the new office completions will be located in the motorway corridor.

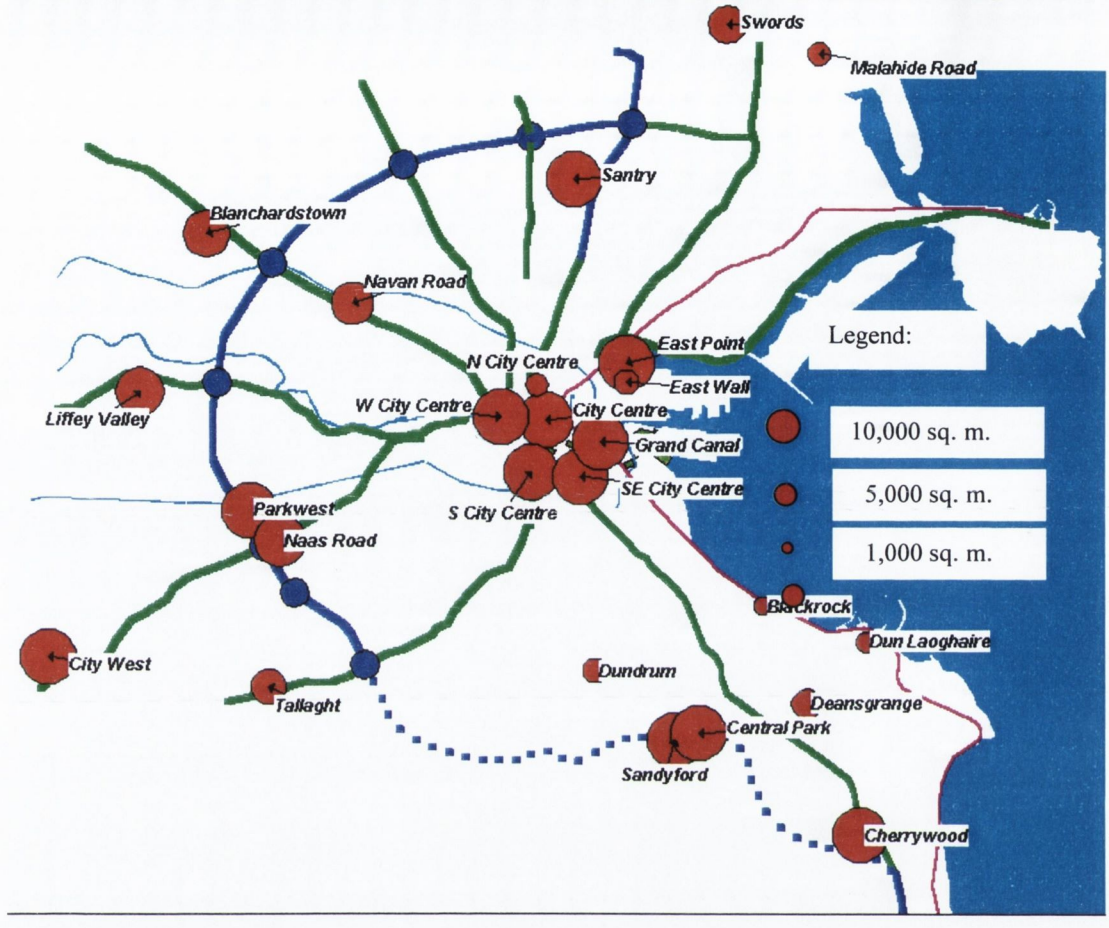

Figure 3.10: Dublin Office Completions 2001, 2002 (Source: Lyster pers comm.)

3.8.4 Future transport in Dublin

In the first major step in co-ordinating transport and land-use planning the latest transport plans published by the DTO (2000a) do take account of the Strategic Guidelines and aim to complement them. The transport strategy is composed of two key elements:

- Demand management: reduction in growth of travel without hindering the economy, through the transfer of peak period trips to more sustainable modes such as public transport, cycling and walking, and
- Infrastructure and service improvements: expansion of public transport network along with construction of some strategic roads.

As shown earlier in section 3.5.3 the total peak hour trip demand is expected to be 488,000 in 2016, with radically different travel patterns than those in the early '90s. The proposed public transport network, shown in Figure 3.11, will cater for 300,000 trips in the morning peak hour in 2016. The largest change that is proposed is the quantity of rail based public transport.

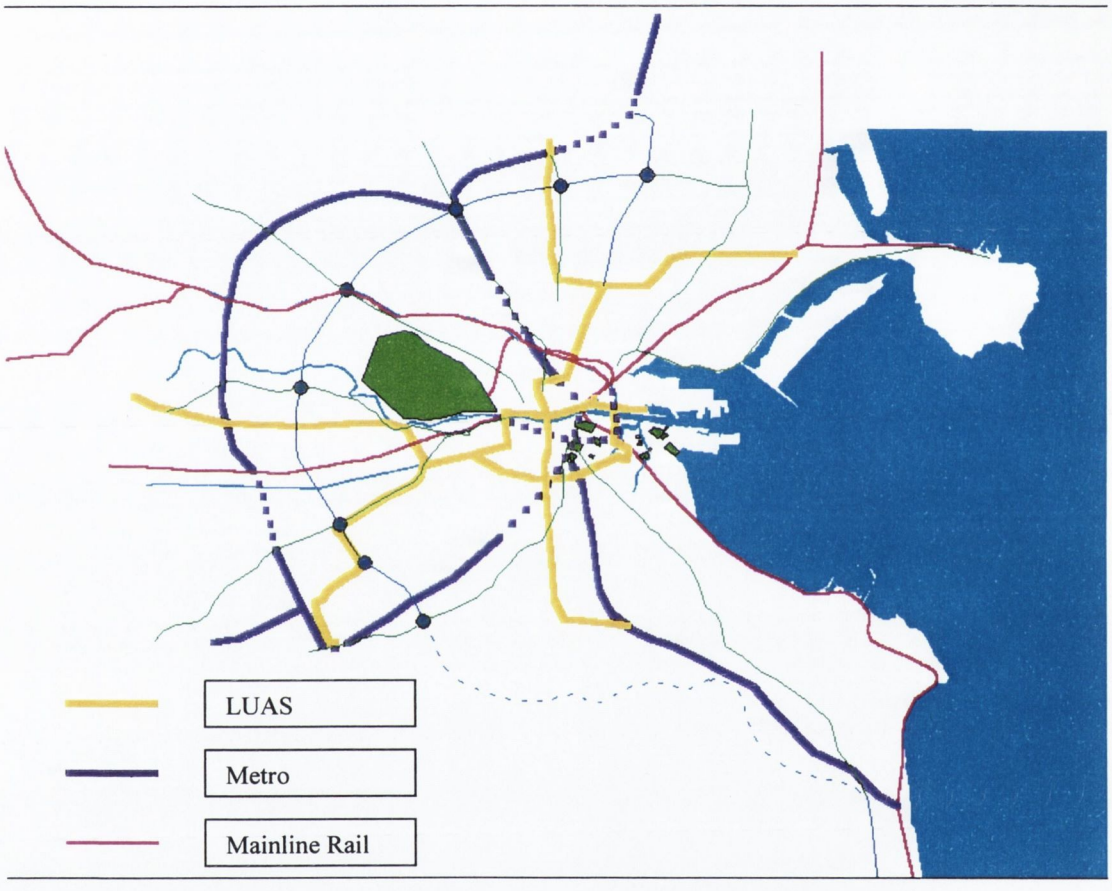

Figure 3.11: DTO Proposed Public Transport Network (Source: based on DTO 2000a)

Figure 3.11 shows the proposed network of rail including suburban rail, metro and LUAS. The following are the principal elements of the public transport network:

- Underground rail connector linking Heuston with East Wall junction via Pearse Station and Docklands,
- Metro system including orbital route Dublin Airport to Tallaght,

- Extended LUAS network including south city ring.

It is the aim that in the long term the bus service will be used to feed passengers to these rail services as well as carry them to their destination (DTO, 2000a). Additional radial and orbital QBCs will be built to enable this to happen. In effect the strategy will create a mesh of public transport services to allow people to make complex journeys including suburb to suburb by public transport.

In addition there are plans for suburban rail developments that will open up outlying areas for further development. Both the Kildare and Maynooth lines will be electrified and the route from Connolly to north of Howth junction will be four tracked and so will the route from Cherry Orchard to Sallins. The Navan railway line will also be reopened – this area is identified in the Strategic Planning Guidelines as an area with significant development potential.

The DTO will continue to extend and improve the elements of traffic management that have been implemented from DTI. This will include:

- Expanded cycle network and provision of cycle parking at public transport stations,
- Improved pedestrian facilities,
- Continued development of traffic cells in the city centre.

Some of the demand management measures proposed for further study include:

- Road pricing.schemes,
- Charging for workplace parking spaces,
- Mobility management plans by employers.

It is pointed out in the DTO strategy that for it to be effective, then all land use developments should be consistent with the Strategic Planning Guidelines. Some specific points are made in the strategy relating to land use as follows:

- Developments that generate high volumes of trips should be located in a public transport corridor,
- A parking strategy should be developed for the GDA to determine the maximum quantity allowable in new developments,
- Local development authorities should seek to increase densities of development in locations close to public transport.

Table 3.9 shows the projected modal split for 2016 following implementation of the strategy. The key point to note is that the number of car trips stays at 1997 levels whilst bus and rail carries the projected growth in travel.

	1997		*2016*	
Bus	47,000	19%	69,000	14%
Rail	21,000	8%	239,000	49%
Car	181,000	73%	180,000	37%
Total	*249,000*	*100%*	*488,000*	*100%*

Table 3.9: Mode Split in the AM Peak Hour (Person Trips) (Source: DTO, 2000a)

Interestingly there is no mention of the growing trend for people to live closer to their place of work and so walk or cycle to work. The strategy does not pay any attention to one of the key sustainable aims proposed earlier, which was to reduce trip lengths. In fact the public transport strategy could have the opposite effect of increasing trip lengths. New and faster connections will open up new job opportunities and enable people to consider longer journeys not feasible before.

3.8.5 Future Administrative Structures

A number of changes are proposed for the way in which transport and land-use are planned and provided. The two key changes proposed are:

- Controlled deregulation of the public transport market, and
- Establishment of Greater Dublin Authority.

In August 2000 the government published a consultation document on proposals for deregulating the public transport market. In the document (DoPE) the following key points were made:

- The public transport market should be opened up to private participation to improve quality and efficiency,
- The government through some public transport regulatory body would broadly define what standard of public transport services are required,
- Finance the developments from government or by organising the setting up of public private partnerships.

In this consultation document the government proposed that the exact form of the regulatory body would be determined when the establishment of a Greater Dublin Area Authority was being researched. It is proposed that this GDAA would determine the strategic land-use and transportation plans for the GDA. In a consultation paper (DoELG & DoPE) some of the functions of the proposed body are set out. These include:

- Preparation of a long term (15 – 20 year) land use and transportation strategy for the area,
- Adoption and monitoring of shorter term implementation and action plans,
- Allocation of finance to implementing agencies,

- Promoting and regulating an integrated public transport network.

Figure 3.12 shows how the new body would fit into the current institutional arrangements in Dublin. It would subsume some of the functions and powers of the DTO, Strategic Planning Steering Committee and CIE, but in a more effective manner.

The Dublin Chamber of Commerce is very vocal in its support for the establishment of such an authority. It says that centralised management works well in other European cities and that London is now also moving in this direction with the establishment of the Greater London Authority (IT, 11/1/01a). According to McDonald (IT, 5/1/01) the prime motivation for creating the GDAA is to control the large-scale rezonings that are occurring in the outer counties of the GDA.

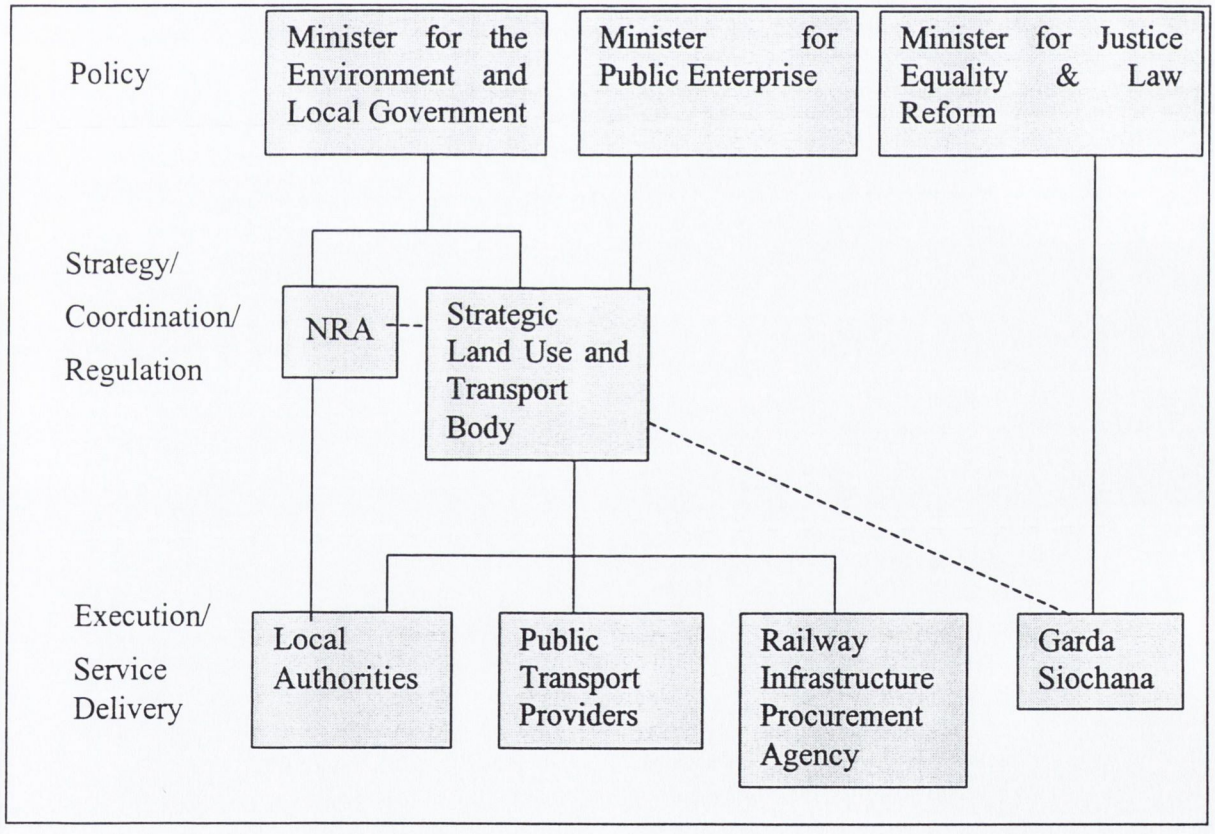

Figure 3.12: Future Hierarchical Planning Arrangements (Source: DoELG & DPE)

3.8.6 Summary of Future Plans

A large number of changes in land-use and transport planning are in the process of occurring in Dublin. The key changes that have been documented here are as follows:

- Land-use planning system has been revamped with a hierarchical system of plans that has statutory recognition. These plans must adhere to the principles of proper planning and sustainable development.

- Regional Plans such as the Strategic Guidelines (Brady, Shipman & Martin 1999) for the GDA must be adhered to by the local authorities when thery are compiling their development plans.

- Density in Dublin Corporation Borough is 42 pph and according to the Strategic Guidelines will only rise to 44 pph. This is below the recommended density lower limit of 50 pph for sustainable urban development.

- Problems getting local authorities to comply with guidelines.

- Location of employment not considered in Strategic Guidelines. It is shown that over 50% of new office completions in 2001 and 2002 will be located in the M50 motorway corridor.

- New public transport plans produced by the DTO take account of Strategic Guidelines. Aim of plans is to cater for estimated increase in trip making with public transport. This will require extensive public transport infrastructural investment.

- DTO recommends the following necessary complementary measures:

  – Higher densities of housing should be located in public transport corridors,

  - Developments that generate high volumes of trips should be located in public transport corridors.

  - Parking strategy should be developed for the GDA,

- No provision made for reduction in trip distances in either DTO plan or Strategic Guidelines and increase in walking and cycling.

- Deregulation of public transport and establishment of Greater Dublin Authority. This will have the effect of providing a more coordinated approach to land-use and transport planning in the GDA and more efficient provision of public transport.

3.9 Dublin Docklands Redevelopment

3.9.1 Planning

The regeneration of the Dublin Docklands began with the Custom House Docks development. In November 1986 the Custom House Docks Development Authority was established to transform a walled enclosure of under-utilised warehousing to a vibrant, living part of the city. The Authority managed to stimulate the development of:

- 112,000 sq.m. of office space,

- 333 apartments,

- 234 bedroom hotel,

- Ireland's only trading exchange,

- Retail, restaurant and pub facilities,

- Public amenity space and car parking

There were many incentives given to companies to locate in the new development. Some of the key incentives provided for the Custom House Docks Area were:

- 100% Capital Allowance for owner-occupier developments in Year 1,
- Companies pay Corporation Tax at a special rate of 10% for first 10 years of lease,
- Double rent relief for commercial buildings for first 10 years of lease.

With reference to these incentives it is no wonder that the new development has occurred quickly and is still expanding. Following on from this success the Government decided that a strategic approach should be taken to developing the whole of the Dublin Docklands. A new authority was established on the 1 May 1997, called the Dublin Docklands Development Authority.

The duty of this Authority is outlined at the beginning of the Master Plan (DDDA, 1997) and is to secure:

I. the social and economic regeneration of the Dublin Docklands Area on a sustainable basis,

II. the improvement of the physical environment of the Dublin Docklands Area, and

III. the continued development in the Custom House Docks Area of services of, for, in support of, or ancillary to the financial sector of the economy.

The Authority's objectives are set out in detail in this Master Plan and this section will look at the land-use and transportation objectives before describing what has been achieved in these areas to date.

There has been much change in the Docklands Area in the last 22 years. Residential and office uses have been expanding into traditional industrial and warehouse areas. This change is now happening quite dramatically with many new developments taking

place. These new developments will result in an increase in the residential population of the area as well as increased employment opportunities. The Master Plan aims to guide this development by pursuing a policy of mixed-use development, which will achieve a sustainable environment and integrate living, working and leisure locations.

The two principal objectives contained in the Master Plan with reference to residential development are:

- an additional 25,000 people living in the area in fifteen years time, and
- development of social and affordable housing at a minimum average of 20% of all new units.

The second point here has caused much debate amongst developers as it is not yet clear whether the social housing must be integrated into each residential development or if a developer can purchase land elsewhere to develop his quota of social housing. This is now a city wide requirement for housing developments (IT, 29/8/00).

The Master Plan also contains some stipulations as to where commercial developments should be located. It says that the Authority will also be required to provide for the expansion of high-quality office building zones from the existing central business district and locate new office areas around major transport nodes, such as the existing DART[13] stations. The Authority also hopes to develop the emerging category of business space, termed "Type B[14]", in areas north and south of the river that are presently not served by public transport.

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[13] DART, Dublin Area Rapid Transit — electrified rail service on eastern edge of Dublin.

[14] Type B Offices: — non-specific business use, which includes administration, research, dispatch, telemarketing, software and R&D.

3.9.2 Public Transport Proposals Contained in the Master Plan

The Dublin Docklands Master Plan contains a number of transport objectives that have been developed to be in line with the DTI strategy. The principal objectives are:

- Improve the transport system to facilitate greater access to, and improve circulation within, the area,
- Promote the use of public transport, cycling and walking as a practical alternative to the car,

Some of the ways the DDDA proposes should be used to achieve these objectives are as follows:

- Restrictive provision for car parking in some developments within the area whilst providing for bicycle parking facilities,
- Provision of a high quality, flexible bus based system with plans for the implementation of a LUAS extension,
- Multi-modal transport interchanges,
- Provide for and promote the use of cycle and pedestrian routes throughout the area.

A phased implementation of the proposed suggested. The key elements of each phase are outlined below.

Phase I – 1997-2002:

- Docklands Area Bus System (DABS) providing a vital link between the city centre and the Docklands area,
- Environmental Traffic Cell (described in the next section),
- Provision of bicycle and pedestrian facilities.

Phase II – 2002-2007:

- Construction of Macken Street Bridge (DTI proposal),
- Possible extension of LUAS system.

Phase III – 2007-2012:

- LUAS extension if not completed in Phase II,
- Adaptation of bus system to complement LUAS,
- Rail link to Airport.

As of yet there are no definite proposals to get DABS up and running. The DDDA when approached (Smith pers comm.) said that the DTO should be asked about transportation plans for the area. Dublin Bus when approached (O'Leary pers comm.) said that discussions had taken place with the DDDA but nothing further had happened. O'Leary (pers comm.) said that the DDDA would have to provide some funding in the initial stages as it was not financially viable.

No definite plans for extensions to LUAS have been made but extensions are included in the transport strategy put forward by the DTO (2000). This includes two lines:

- Mayor Street alignment to the Point Depot, and
- North south link over Macken Street Bridge linking to Dundrum line.

The Macken Street Bridge has been designed as a land-mark structure by Dr Santiago Calatrava world leading bridge designer. It consists of a cable stayed structure with a span of 120 metres suspended from pylon with a curved profile leaning northwards. The bridge pivots to allow ships to pass upstream. It will be of sufficient width to carry four lanes of traffic but it is hoped that two of these will be converted to public transport only. The bridges design is such that light rail is a possibility.

The primary purposes of this bridge are:

- to integrate the north and south Docklands, and
- provide a relief route for traffic east of the city centre.

The DTI first proposed a bridge at this point in 1994. The DDDA in their Master Plan (1997) supported this proposal as according to them it would 'create a vital link to both the North and South Quays'. The bridge has also been included in the Greater Dublin Area Strategic Guidelines (1999), National Development Plan (1999) and the Dublin City Development Plan (DC, 1999).

Frank McDonald in the Irish Times (IT, 2/8/20) highlights some of the traffic changes that the bridge will bring about:

- Macken Street → 120% increase
- Guild Street → 190% increase
- O'Connell Street → 23% reduction

This reinforces the strategy of routing car traffic away from the city centre and aids in providing an improved environment in the O'Connell Street area. The bridge is significant in terms of developing city centre environmental traffic cells, bus lanes and cycle tracks.

In linking up the north and south docklands areas there will be a greater possibility that residents of the area will be able to reach their work destination by foot or by public transport. Public transport routes will be able to be reworked to provide more effective links for the local area.

Residents in the area have benefited considerably from the area being opened up for development. Access is improving and house prices are increasing. McDonald points out that some houses have trebled in value on Macken Street (IT, 2/8/00). Some of the residents are mounting a campaign against the bridge because of the large increases in traffic forecast.

3.9.3 Docklands Redevelopment to date

The study area that comes under the jurisdiction of the DDDA comprises 526 hectares. It consists of all or part of 7 electoral wards. The external boundary of the Docklands Area is co-terminus with the edge of 4 of the Wards but it divides the other three of the Wards as shown in Figure 3.13.

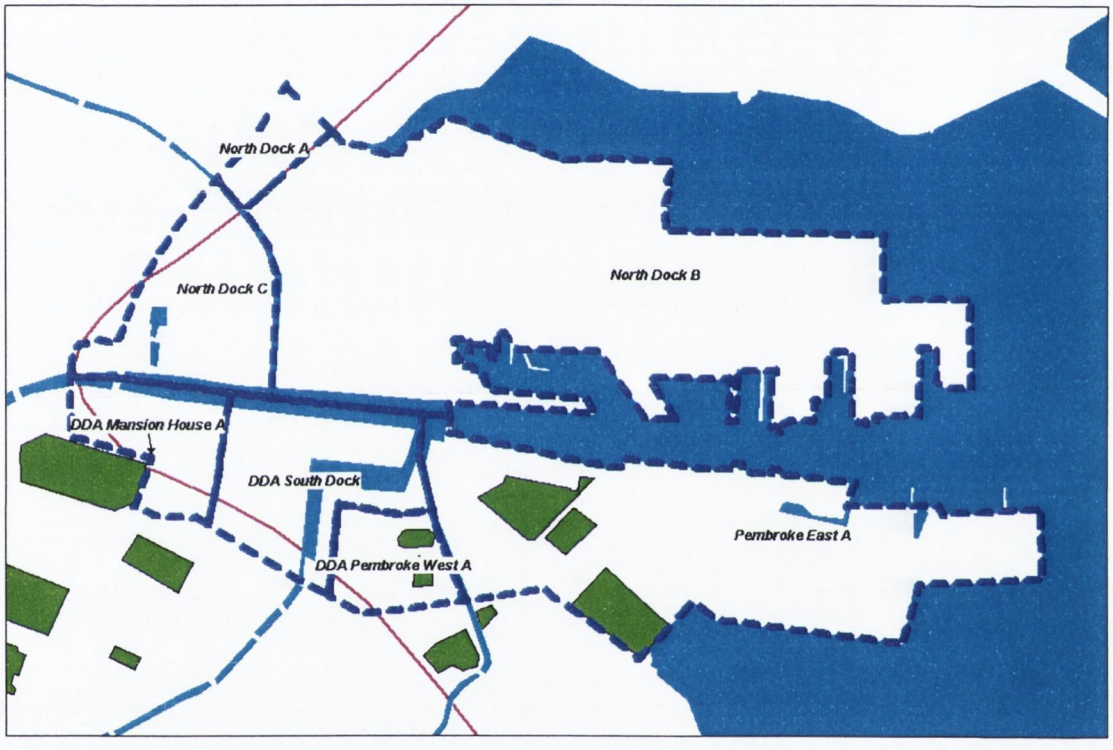

Figure 3.13: Dockland Study Area

The Small Area Population Statistics provides extensive information on each Ward. This means that for the 3 Wards that are divided by the boundary of the study area a weight must be applied to the data to account for their partial inclusion. The weights used are those applied by Collins et al. (1996) in their report on the area for the ESRI and are: Pembroke West A (0.5), South Dock (0.5) and Mansion House A (0.8). When the letters DDA (Dublin Docklands Area) precede a ward then the partial ward is being referred to.

Table 3.10 shows the change in total population over the period between 1966 and 1996. The North Docks refers to the three wards north of the Liffey whilst the South

Docks refers to the whole of the 4 wards south of the Liffey. The wards are not reduced to their parts contained within the study area as it is was decided that the factors would not necessarily be consistent over such a period of time. It can be seen that the whole area has experienced a decrease in population during this thirty year period. The principal drop occurred in the 1970s and in the period up to 1991 the downward trend continued more slowly. In the early 1990s this trend has been reversed and the population of the area is now increasing.

	1966	*1971*	*1979*	*1981*	*1986*	*1991*	*1996*
North Docks	13548	12035	9107	8510	8063	7049	7254
South Docks	21397	18460	15082	14695	13645	13097	14087
Total	34945	30495	24189	23205	21708	20146	21341
		-12.73%	-20.68%	-4.07%	-6.45%	-7.20%	5.93%

Table 3.10: Total population 1966-1999

Data for the age structure of the population of the Docklands has been compiled using the partial wards so that the statistics refer only to the Docklands Area. Figure 3.14 shows that an increase occurs in the 25 – 44 age bracket during the period 1991-96. There is a small increase in the 15 – 24 group whilst the other age groups all show a decrease. The increase in the 25 – 44 age group means that there is an increase in the working population of the area.

Table 3.11 show that there is an overall increase of almost 700 households in the time period 1991 – 1996. The principal increases occur in the number of flat/bed-sit units on the southside and the number of conventional housing units on the northside.

- 2,065 flat/bed-sit units in 1996 compared to 1,729 in 1991 on the southside,

- 2,312 conventional houses in 1996 compared to 1,983 in 1991 on the northside.

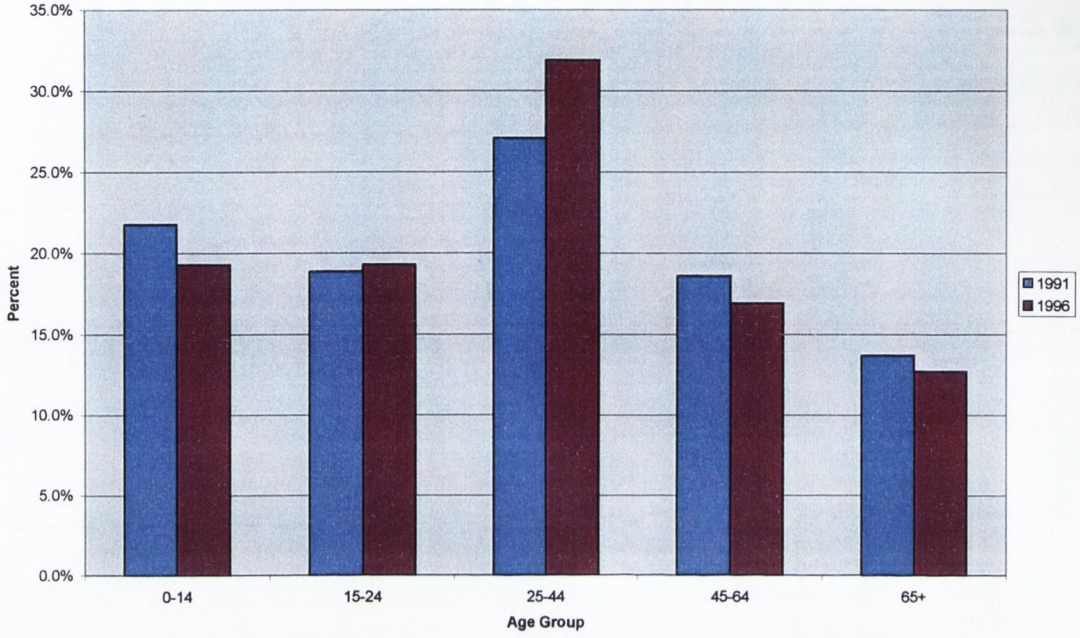

Figure 3.14: Population Age Breakdown Comparison between 1991 and 1996.

Area	*Conventional House*		*Flat/Bed-sit*		*Other*		*Total Households*	
	1991	*1996*	*1991*	*1996*	*1991*	*1996*	*1991*	*1996*
DDA Southside	1842	1913	1729	2065	23	7	3594	3985
DDA Northside	1983	2312	456	418	9	0	2448	2730
Total DDA	3825	4225	2185	2483	32	7	6042	6715

Table 3.11: Households 1991 – 1996

3.10 Summary of the Development of Dublin

The following key points have been made through this chapter:

- Up until 1999 with the enactment of the new planning bill (ref) and the adoption of the Strategic Guidelines (ref) there has been little co-ordination between land-use and transportation planning.
- Public transport in Dublin is provided by a state owned company but is not properly integrated as in other countries in continental Europe.
- Many reports planning the development of Dublin have been produced but in each case only part of each strategy were implemented.
  - A comprehensive suburban rail system was proposed for Dublin but only the DART along the east coast was implemented.
  - The 3 western towns were developed as residential zones as recommended but facilities and public transport were not provided to the required standard.
- DTI was the largest transport planning exercise undertaken in the state but had no land-use planning jurisdiction and no land-use plan to refer to.
- DTI strategy focused on reinforcing the vitality of city centre and not allowing car to dominate.
- Transport planning in the DTI process and currently by the DTO focuses on car, rail and bus and does not adequately consider cycling and walking.
- DTO organises transport strategy but does not directly implement it.
- QBCs have been implemented with much success in some areas of the city.
- Significant delays to LUAS.

- Traffic growth in the Dublin area has been way beyond forecasts in DTI.
- New travel patterns have developed that are a function of the lack of control of the location of new work places. The focus of much new development is the M50 corridor.
- New transport plans focus on catering for increased demand with extensive public transport. There is no focus on reducing trip distances and increasing walking and cycling.
- Prescribed densities in city centre are still not as high as those put forward as being required for a sustainable urban environment.
- New planning bill does put forward sustainable ideals.
- Future planning structures should provide a more integrated approach to transport and land-use planning.

All of these points show that the development of Dublin has been mismanaged and has allowed the city to develop in a car-orientated manner. The aim of the new plans is to absorb the increase in trips through extensive public transport provision. This is in line with creating a sustainable urban environment but the lack of measures to reduce trip lengths through land-use planning is not.

The Docklands area is a key redevelopment area in the city and will cater for additional population in close proximity to the city centre. This area has the potential to be developed in a very sustainable manner.

Chapter 4

Neural Networks

and

Mode Choice Modelling

4.1 Introduction

A key motivation for this work has been to establish a fair and efficient mode choice model. Ortúzar and Willumsen (1994) say that that mode choice "is probably the single most important element in transport planning and policy making." In many models the public transport option seems to be the second class option. This was the case with many modal split models in the USA where there was a background assumption that as income grew people would seek to acquire cars and use them (Ortúzar and Willumsen, 1994). It was also shown to be the case in the Dublin transportation model in chapter 3. The primary choice is made between public transport and car, resulting in the full benefits of a new public transport service not been seen at the decision point.

Many mode choice models tend to start with the premise that people wish to travel by car and then look to see how they can be dissuaded. This is in contrast to experience of modern cities today where many white-collar workers are seen travelling to work by public transport. Other models have as their base statistic the number of vehicle trips. The use of public transport and slow modes is calculated as a negative or positive shift. Both of these methods produce an inherent bias towards car use.

The majority of models appear to assume that the base unit of travel is the vehicle. This thesis will attempt to show that a more realistic model can be developed if the real base unit, the person, is used. To capture the real mode choice decision it is necessary to approach the topic at the individual level of each person trip. If we can identify why people choose different modes for particular journeys then a better estimation of mode choice can be achieved.

The factors involved in the choice can be many and are often diverse. It is the difficulty in capturing the connections between independent variables and choice that has given rise to many different types of modelling solutions. A subsequent section will briefly review some of the different mode choice models in current use.

It is proposed to develop a new style of mode choice model inspired by the neural structure of the brain. These models, called neural networks, have already been used in different branches of learning such as artificial intelligence, pattern recognition, biology and psychology (Maren et al., 1990). They have many benefits over traditional models and this chapter will explore this type of model.

Firstly, a background to neural network models will be presented followed by an overview of how the models have been used in transport applications to date. The final sections will investigate how it is proposed to apply a neural network in a mode choice application.

4.2 Neural Networks

Maren gives a definition of neural networks as follows:

> "Neural networks are computational systems, either hardware or software, which mimic the computational abilities of biological systems by using large numbers of simple interconnected artificial neurons" (Maren et al., 1990).

Artificial neurons are a simple representation of biological neurons, in that they take in information, perform a simple operation on it and pass it on to other artificial neurons. The ability of neural networks to solve particular problems is related to their structure, dynamics and learning methods (Maren et al., 1990).

Almost all neural network architectures are composed of a set of interconnected nodes that accept input, process this information in some way, and produce an output that is passed along to other nodes. A schematic diagram of a simple backpropagation network is shown in Figure 4.1. This network has 2 input nodes, 3 middle layer[15] nodes and 2 output nodes. The nodes are connected to all of the nodes in the subsequent layer by a weighted link. In a backpropagation network the information is passed forwards through the layers until the output layer is reached. The word

[15] Also know as hidden layer.

'backpropagation' refers to the learning process in which adjustments are propagated back through the network to reduce the error terms. The process will now be explained in detail starting with the passing of information forward through the network.

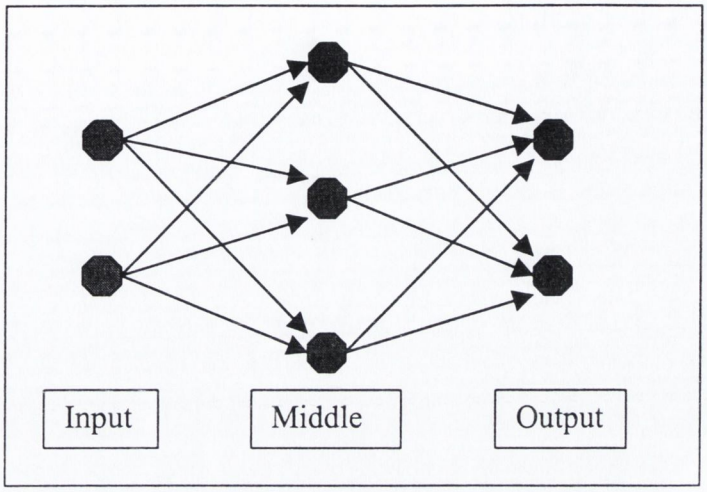

Figure 4.1: Backpropagation Neural Network (Source: Rogers, 1997)

The network reads in an example set of input-output pairs. Each input layer node is assigned one of the input pattern component values. The nodes in the next layer receive the input node values through the weighted links and compute output values of their own to pass to the next layer. This process is repeated through the network until each output layer node has calculated a value and this is taken to be the generated output.

The transfer function is the principal computing part of a node. Different transfer functions can be used depending on the application. Maren (Maren et al., 1990) discusses three different types of transfer function as follows:

Threshold transfer function: activation of the node is defined as being binary – either 0 or 1.

$$F(x) = -1.0 \quad x < 0$$

$$= 1.0 \quad x \geq 0$$

Hard-Limit Nodes: both upper and lower bound are set on the summed input from other nodes. Outputs are defined as follows:

$F(x) = 0$ for $x < \alpha_1$

$=$ linear function of x between 0 and 1 for $\alpha_1 < x < \alpha_2$

$= 1$ for $x > \alpha_2$

where α_1 and α_2 are the lower and upper bounds respectively.

Sigmoid transfer function: the use of a smoothly varying function allows learning methods to differentiate the output activation. The ability to differentiate the output is necessary in backpropagation networks as will be explained subsequently. The equation is as follows:

$$f(x) = \frac{1.0}{1.0 + e^{-x}} \qquad \text{.....Equation 4.1}$$

This function is shown in Figure 4.2 for $-10 \leq x \geq 10$.

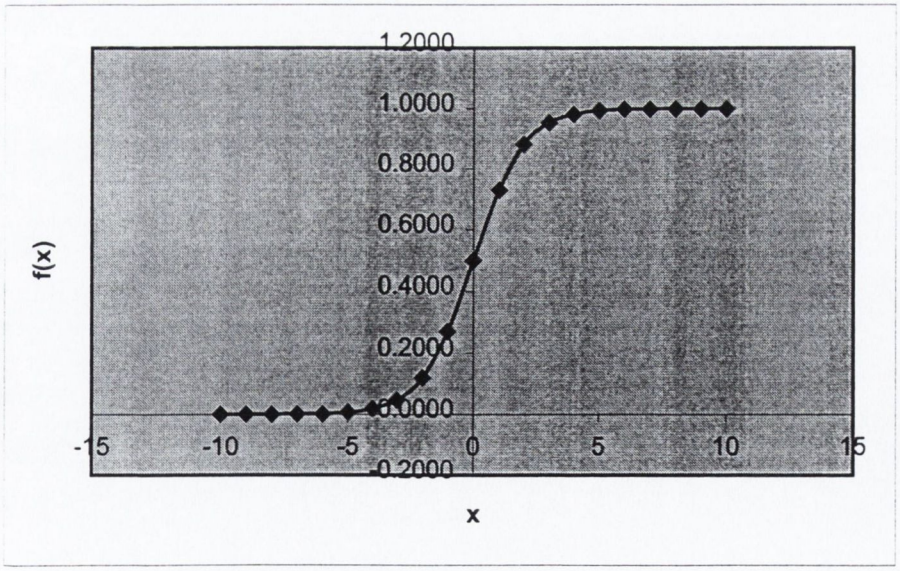

Figure 4.2: Sigmoid Transfer Function

The training process is probably the most significant and distinctive feature of neural networks. Training is undertaken using an iterative process during which the network weighted links are adjusted until the network can distinguish which inputs or pattern of inputs leads to a certain decision. A supervised method of "minimum error learning" is used which calculates the required adjustment of the weighted links. These adjustments are calculated and made after each input-output pair has been applied to the network. This type of training process distinguishes neural networks from other styles of models.

An error signal is computed by comparing the actual output with the generated output. This error is propagated backwards through the network with the weight on each link being adjusted according to its relative contribution to the total error. The example set is presented to the network repetitively until the network has converged so that all the training patterns in the set are encoded. The value that the 'tolerance' parameter is given has a bearing on when all of the training patterns are considered to be encoded. The 'tolerance' is a value that gives the allowable tolerance between the actual output and a generated output before the generated output is considered to be a correct output. Training can be stopped when all of the outputs are considered to be correct.

Sometimes though training is continued until the 'total error' term is below a certain value. The 'total error' is a sum of all the error terms over the whole data set. This 'total error' is usually compared to a 'max error' term which is user defined. A network can be over-trained leading to less effective predictive powers. Once training is complete the network can be presented with new input patterns, from which it can produce an output based on the experience that it gained from the learning process.

The backpropagation error surface is nonlinear and quite complex – Figure 4.3 shows a pictorial representation of the error against the iterations. The training method tries to minimise the overall error and so the overall error result is moved down the error surface by each iteration. Due to the nature of the complex surface, the network can get stuck in a local minimum. Over-training can also result in the network being pushed into a local minimum. A momentum term is used, which adds a percentage of a link

value's previous change to the current change. This can often push the network through local minima.

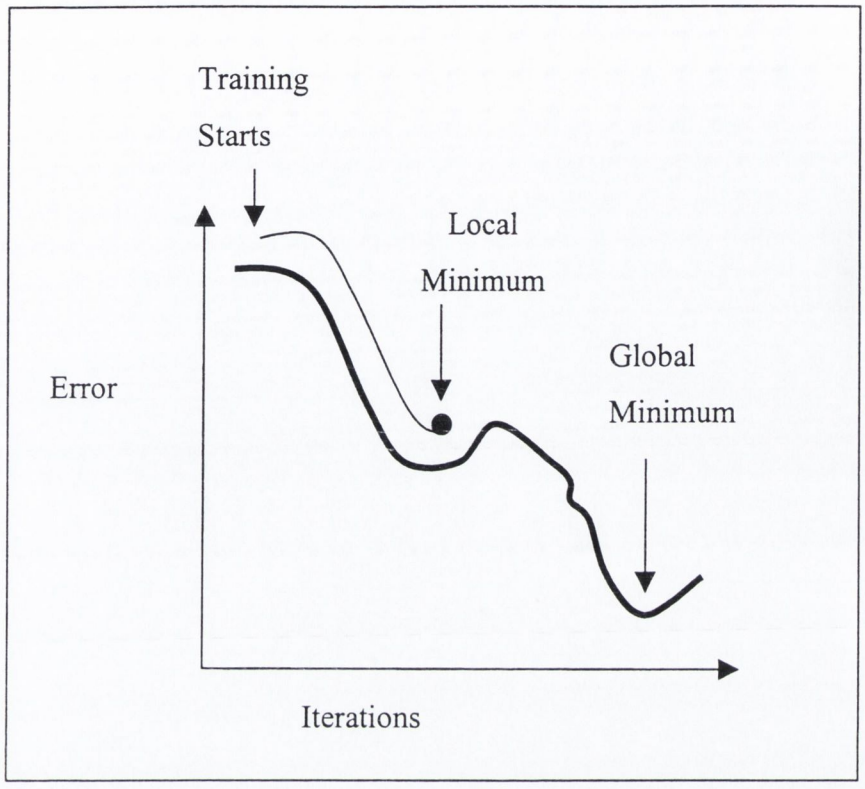

Figure 4.3: Local Minima and the Backpropagation Neural Network (Source: Rogers, 1997)

One of the most commonly used training algorithms for backpropagation neural networks is the generalised delta rule. It is through the application of this learning method that the neural network can discover its own algorithms. These relationships are likely to be non-linear, as well as multidimensional. The iterative learning algorithm is shown in Figure 4.4 and it is called the *steepest-descent technique.*

A strict least-squares method would require that all of the weight values should be changed once all of the training patterns have been presented to the network once. Freeman & Skapura (1991) say that there is little benefit in taking that approach in backpropagation networks and recommend that weight updates are performed as each training pattern is processed.

1. Apply an input vector to the network and calculate the corresponding output values.
2. Compare the actual outputs with the correct outputs and determine a measure of the error.
3. Determine in which direction (+ or -) to change each weight in order to reduce the error.
4. Determine the amount by which to change each weight.
5. Apply the corrections to the weights.

Figure 4.4: 'Steepest-Descent Technique' Algorithm (Freeman & Skapura, 1991).

It has been shown that during training backpropagation neural networks develop internal relationships between nodes (Maren et al., 1990). This means that the nodes in the hidden layers organise the connections between themselves such that different nodes learn to recognise different features of the input. Certain nodes will respond with an active output if the new input contains a pattern that resembles the feature that they learned to recognise during training. This active output will be propagated forward to the relevant output node and participate in increasing that node's output value. When a feature is absent from a pattern then the nodes will tend to inhibit their outputs. This means that the value propagated forward to the relevant output will be greatly reduced and so participate in reducing that node's output value.

Maren et al. (1990) also show that the network can work with incomplete or noisy patterns and recognise subtle patterns from the partial input. This feature-detection which is trained into the hidden layer nodes means that the network can make complex distinctions when presented with a pattern that is different from that which the network was trained on. It is the ability to make these decisions that makes the applications of neural networks so powerful.

When a network reaches a stable point there is no guarantee that it has reached a global minimum rather than a local one. The true measure of the networks performance is how well it can match input patterns with the correct output patterns. Maren et al.

(1990) suggest that some fraction of the data should be reserved for testing the trained network. This allows the ability of the network to produce outputs on unseen data to be tested. If the network is not predicting outcomes very accurately it will be necessary to restart the training process making some adjustments on some of the parameters.

Freeman & Skapura (1991) recommend that random selection of training vector pairs is good practice. Non-random selection could result in a group of similar data sets causing a bias in the learning process.

The network configuration can be changed to aid the training process. This involves deciding the number of layers and the number of middle layer nodes. Generally 3 layers is sufficient (Maren et al, 1990) but according to Freeman & Skapura (1991) some problems train faster with more than one middle layer. There is more scope for change in determining the number of middle layer nodes. The fewer middle layer nodes used the less processing power required but the network may not be able to reach a satisfactorily trained solution. Conversely if too many middle layer nodes are used then the network may train successfully but not perform as well on test data. This may mean that the network's ability to detect the necessary patterns in the input data has been lost due to it focussing on a local minimum and losing its ability to generalise. Therefore a balance is required in the selection of the number of middle nodes between achieving successful training and maintaining feature detection abilities. This issue will be investigated in detail when the neural network mode choice model is being developed.

There are two key network parameters, which must also be adjusted to aid the network in achieving the best solution. The two parameters learning rate, η, and momentum, α, determine by how much the weights in the network should be changed after each data item is presented to the network. The learning rate determines how much of the error should be propagated back through the network. To ensure the network settles on a solution its value is usually small and in the range of 0.05 – 0.25. The larger η is, the fewer the number of iterations required, however the network may tend to oscillate

around the minimum value instead of actually reaching it. A small η will allow the network to settle on a solution but may take a large number of iterations to achieve it.

The momentum parameter is used to help keep the weight changes going in the same direction by adding a fraction of the previous change. The parameter, α, is usually set to a positive value less that unity. The weights on the network links are initialised to random values between +/-1.0.

4.3 Object-Oriented Neural Networks

4.3.1 C++

C++ is an extension of the original language C that provides the capabilities for object-'orientated programming'. Software 'objects' are basically reusable sections of code that model particular items. A key motivation for this style of programming is the speeding up of software development. A particular program might be broken up into a number of objects. This might enable a team of people to develop a program with each person working on a particular 'object'. A program might also be able to make use of previously developed 'objects' with some minor adjustments.

An object in C++ is created in the form of a 'class'. A 'class' consists of two principal parts. The first is data members to store the object's data. The second is a series of functions to provide procedures that the 'class' will have to be able to perform. A basic 'class' maybe created such that it can be adapted to form different types of objects that have some similarity.

An example of this might be a 'class' that models a basic calculator. This 'class' would have data members to temporarily store the numbers entered and functions that would be called for the various calculations. Another 'class' could be developed from this that models a scientific calculator with all the extra functions. This second 'class', known as the 'child class', can inherit all of its parent's structure, in this case the standard calculator functions. It can then add in the extra scientific functions as well.

4.3.2 Neural Networks in C++

Due to the way that all neural networks are made up of similar building blocks of nodes and links they are ideally suited to be implemented in an object-oriented manner. Base classes can be developed that are flexible enough to model a wide range of neural network applications. Rogers (1997) has developed classes that provide such a basis. It was necessary to develop a formalisation for the neural network which was flexible enough to model a wide range of architectures. Rogers finds the necessary background material in Fiesler (1992, 1994) and Rogers and Satyadas (1994).

The backpropagation network developed in this thesis is based on Rogers' work. In the main the base classes are left as they were developed by Rogers whilst some of the higher level classes have been adapted to suit this particular application. The following description of the network is primarily about the basic functionality developed by Rogers whilst the adaptations for this thesis will be discussed in a later section.

Two base classes called **Base_Node** and **Base_Link** form the starting point of the network. These two classes are interdependent and all of the other classes are derived directly from them. The **Base_Node** hierarchy is shown in Figure 4.5 and the **Base_Link** in Figure 4.6.

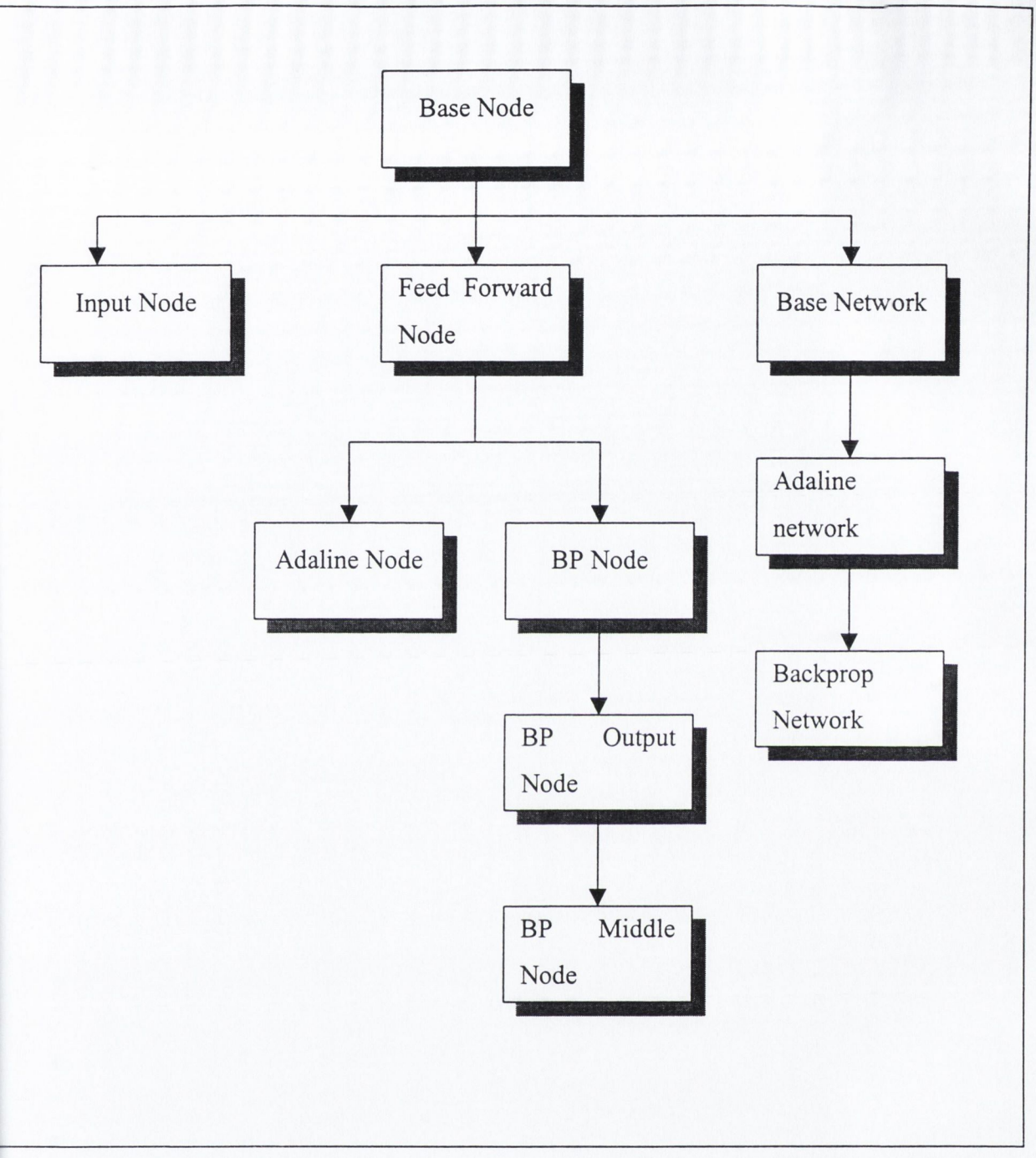

Figure 4.5: Class Hierarchy for Neural-Network Nodes (Source: Rogers, 1997)

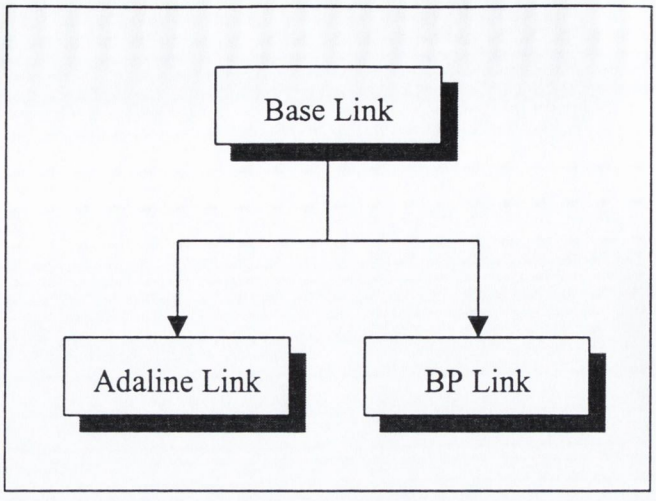

Figure 4.6: Class Hierarchy for Neural-Network Links (Source: Rogers, 1997)

Two other independent classes act as helper classes and provide two important roles:

- **LList** objects consist of a doubly-linked list that stores **Base_Link** pointers. One list holds pointers pointing to all the of the link objects bringing input to the node object from other nodes whilst the other list holds a list of pointers pointing to all of the link objects connecting the node object to its destination node.

- **Pattern** objects are primarily arrays of double values which provide the functionality to store the required input patterns and output patterns that a neural network operates on.

The **Base_Node** class manages two primary operations:

- the receiving of input values,

- the distribution of the processed information to other nodes in the network

This class does not define how the node processes information. It maintains the connections between the network nodes using **LLlist** objects in each **Base_Node** object.

The **Base_Link** objects referenced in the **LList** object hold two **Base-Node** pointers, one pointing to the source node and the other pointing to the destination node. The link

objects also maintain values and provide operations that are used in the neural network architecture training and operation.

Run and **Learn,** functions which are fundamental to the neural network process, are defined as virtual functions in child classes.

An adaline[16] is a form of neural network, which can sort a set of input patterns into two categories. The network consists of two layers – an input layer and an output layer. Child classes are written based on the two base classes **Base_Node** and **Base_Link** to provide the functionality for this network. Reference to the adaline is included here because the network is devised in such a way that it develops the building blocks that will be used later on for the backpropagation network.

A number of new node classes are created from **Base_Node:**

- **Input_Node** class is only slightly more complex then **Base_Node**. The value and error sets are instantiated with sizes of one.

- **Feed_Forward_Node** class is common to all feed-forward architectures in that it produces its value by summing the products of its inputs and associated link values and then running this value through a transfer function (f). The formula for calculating the node value is as follows:

$$n_{i,j}(t+1) = f\left(\sum_{k=0}^{\|c_{i-1}\|} n_{i-1,k}(t+1) \times w_{i-1,k \to i,j}(t)\right) \quad \text{.....Equation 4.2}$$

$$where: 1 \le i \le LN$$
$$and: 0 \le j < \|c_i\|$$

- LN is the number of layers and c_i is the number of nodes in that layer. The node value is defined by 'n' and the link values are weights defined as 'w'.

---

[16] Originally ADAptive LInear NEuron it now stands for ADAptive LINEar Element.

The indexes '*i*' and '*j*' refer to the nodes layer and number. The nodes are numbered continuously starting at zero for the first input node. The indexes on the weights identify the position of the starting node and terminating node of that particular link.

- The **ADALINE Node** is created from a general **Feed_Forward_Node** class and defines its own transfer function.

Each architecture of neural network would have its own node created from the general **Feed_Forward_Node** class which allows each individual architecture to define a particular functionality for its transfer function. Rogers (1997) devises the backpropagation network by constructing an adaline network first and then building on top of that.

The **Run** operation is provided with functionality in the **ADALINE Node** and it sums the products of all of the node's link values and their corresponding input values. The **Learn** operation also gets its own functionality and in this case will only be executed if the **ADALINE_Node** produces an incorrect output.

An **ADALINE_Link** Class inherited from **Base_Link** is also created and implements the weighted links used by the architecture.

To further simplify the creation of a neural network, a class called **Base_Network** is derived from **Base_Node** that stores all the components of the network. This is done using two data member arrays, one of which stores pointers to **Base_Node** and the second contains pointers to **Base_Link** objects.

An **ADALINE_Network** class is derived from the **Base_Network** class. This class provides the unique functionality required for that type of neural network. A function called **Create_Network** implements an ADALINE network of a size that is already specified.

The **Run** and **Learn** operations are redefined in the **ADALINE_Network** node. The computation is done with the network **Run** operation, if the data produces an incorrect

output, the network **Learn** operation is executed, otherwise the number of good patterns (**good**) is incremented. When training is complete the network can be used to run new patterns using the **Run** operation.

As mentioned earlier the adaline provides much of the functionality required for the backpropagation network. A backpropagation network has a layered structure which allows it to escape the ADALINE's linear separability limitation.

The **Input_Node** created for the adaline is used directly whilst a few more backpropagation specific nodes are derived from the **Feed_Forward** node.

BP_Node redefines the virtual transfer function to be a sigmoid function as in equation 4.1. **BP_Output_Node** Class is derived from the **BP_Node** class. The **Learn** operation is defined by implementing the delta rule:

Link Values $$w_{i,j\to 1,l}(t+1) = w_{i,j\to 1,l}(t) + \Delta_{i,j\to i+1,l}(t+1) + \alpha\Delta_{i,j\to i+1,l}(t)$$

.....Equation 4.3

Delta $$\Delta_{i,j\to i+1,l}(t+1) = \eta E_{i+1}(t+1) n_{i,j}(t+1)$$ .....Equation 4.4

where $1 \le i < LN - 1$

and $0 \le j < \|c_i\|$

and $0 \le l < \|c_{i+1}\|$

and α is the momentum term

and η is the learning rate

and E is the error, which will be defined next

An output layer node and a middle layer node differ in the way in which the error term (*E*) is computed for the delta rule. The **Compute_Error** operation is placed in a separate virtual function that will be redefined in the **BP_Middle_Node** class' implementation. The errors for the output layer nodes are computed using the difference between the node's output and the desired output value. The magnitude of

the link value change will be proportional to the negative gradient. As a result the differences are multiplied by the node's output run through the derivative of the transfer function.

Output Layer Error

$$E_{LN-1,j}(t+1) = f'(n_{LN-1,j}(t+1)(O_{(t \bmod \|I\|),j} - n_{LN-1,j}(t+1)))$$

$$f'(x) = x(1-x)$$

where $0 \le j < \|c_{LN-1}\|$

.....Equation 4.5

BP_Middle_Layer Node is derived from the **BP_Output_Node** class and redefines the **Compute_Error** operation. There are no desired outputs for the middle layer nodes and so a different approach has to be taken. If a node in the middle layer contributes heavily towards the output of an output layer node that produced a high error, it too must have a high error. This contribution is measured by summing the products of the link values connecting the middle layer nodes and their corresponding output node errors. An estimate for the error can be estimated using the following formula:

Middle Layer Error

$$E_{i,j}(t+1) = f'(n_{i,j}(t+1)) \sum (w_{i,j \to i+1,l}(t) E_{i+1,l}(t+1))$$

$$f'(x) = x(1-x)$$

where $1 \le i < LN - 1$

and $0 \le j < \|c_i\|$

and $0 \le l < \|c_{i+1}\|$

.....Equation 4.6

The network links are defined in the **BP_Link** class which is derived from **Base_Link**. Additional value sets are defined to hold the link value (WEIGHT) and the link value's previous change (DELTA).

The **Backprop_Network** class abstracts a complete backpropagation neural network to a single network node class. It is derived from the **ADALINE_Network** class. This

Backprop_Network class stores network information such as: number of network layers, number of nodes in each layer and indexes to the first node in each layer. In a similar fashion as with the **ADALINE_Network** the function **Create_Network** constructs a network where each node is connected to each node in the succeeding layer (fully-interlayer connected).

The **Run** operation performs the forward pass by executing the **Run** operation for all nodes in the network except the nodes in the input layer. The first node operated on is the **first_middle_node** and the last node is **num_nodes** – 1. The **Learn** function performs the backward pass starting with the last node in the network (**num_nodes** – 1) and going backwards to the first middle-layer node (**first_middle_node**).

4.4 Mode Choice solutions

A principal part of mode choice modelling is the examination of human behaviour and the decision making processes regarding transport. If the decision process can be modelled accurately then it is possible to make more realistic predictions of future travel behaviour. Ben Akiva & Lerman (1985) outline the processes involved in any individual mode choice decision into 5 steps as follows:

1. definition of the choice problem,
2. generation of alternatives,
3. evaluation of attribute of the alternatives,
4. choice, and
5. implementation.

Once the first two stages of the process are defined then there are many factors that impinge on the evaluation and choice processes. Ortúzar and Willumsen (1994) divide up the variables that effect a mode choice decision into three categories:

- characteristics of the trip maker,

- characteristics of the journey, and
- characteristics of the transport facility.

Many of the characteristics of the trip maker are contained in socio-economic attributes and four of these are highlighted:

1) car availability/ownership,
2) household structure (children, retired etc.),
3) income, and
4) residential density.

Characteristics of the journey include trip purpose and time of day. Ortúzar and Willumsen (1994) conclude that better trip generation models can be obtained if separate models are used for different trip purposes. A similar effect would be in evidence with mode choice models, in that the choice of mode is closely linked to the trip purpose. This study will focus on the single trip purpose of the journey to work. In addition, it is the trip to work that is most usually taken by public transport. As a result it is for this trip purpose that there exists the greatest potential to create a sizable transfer away from the car.

The characteristics of the transport facility are critical to any mode choice decision. Some of the attributes considered important include:

- relative travel time,
- relative monetary costs,
- availability and cost of parking,
- comfort and convenience,
- reliability and regularity,

- protection and security.

Carpenter and Jones (1983) include a group of variables that relate to the social background of an individual. They conclude from their research that the social values, norms and opinions relevant to transport behaviour can influence mode choice decisions. In addition they conclude that each individual experiences all of the relevant factors differently and so make these decisions in a subjective manner. It is suggested by the authors that such a decision process is very different from that which a researcher or politician would perceive it to be.

In most mode choice models the analyst assumes that rational decisions are made. This means it is assumed that an individual makes a consistent and calculated decision based on his/her objectives. In choice experiments individuals have been observed not to select the same alternatives in repetitions of the same choice situations (Ben Akiva & Lerman, 1985). A probabilistic choice mechanism can be introduced to explain these behavioural inconsistencies. The choice sets must have distinct alternatives otherwise the choice probabilities will be distorted. If two alternatives are similar then the model will tend to over predict the numbers travelling by the similar modes to the detriment of the other modes.

A large majority of mode choice models consider these processes as aggregate problems. This means that they aggregate segments of the population usually by social background and geographical location. Three different types of aggregate mode choice models exist as follows:

- trip-end modal-split models,
- trip interchange modal-split models, and
- synthetic models.

A trip-end modal split model is applied immediately after trip generation. This method means that it is possible to access the characteristics of the different population segments for use in the mode choice model. According to Ortúzar and Willumsen

(1994) this modelling technique was very popular in the USA and it was consistent with the planning view that most people would seek to purchase a car and use it. The model was restrictive though in that the characteristics of the transport system had no impact on the choice of mode. As a result such a model would give no insight into the benefits of a new public transport system.

A trip interchange modal-split model is applied after the distribution model and is more commonly used in Europe. It allows the inclusion of the characteristics of the journeys and so the available transport modes can be factored into the decision. Ortúzar and Willumsen (1994) say that in most models of this type it is difficult to include the trip maker characteristics at this stage of the modelling process.

The final type of model is a group of models called synthetic models. These models are usually generated using the entropy-maximising approach. The proportion of trips travelling from i to j via mode 1, P_{ij}^{1} is given by the following:

$$P_{ij}^{1} = \frac{\exp\left(-\beta GC_{ij}^{1}\right)}{\sum_{k} \exp\left(-\beta GC_{ij}^{k}\right)}$$

.....Equation 4.7

where

GC refers to the generalised cost for the particular trip, and

ß acts as a dispersion factor.

This ß factor has two main roles. It controls dispersion of mode choices with relation to the generalised costs[17] and the choice between destinations at different distances from the origin. Ortúzar and Willumsen (1994) state that this is probably too much for a single parameter to control. They say that many studies add in an additional

[17] The concept of generalised cost is explained fully in Chapter 3.

parameter that consists of the composite cost (usually a weighted average of different modes) of travelling between i and j as perceived by a particular type of person.

Disaggregate models simulate the choices made by an individual traveller. These types of models are known as discrete choice models because the individual traveller is modelled as selecting from a finite set of alternatives. The decision maker chooses the alternative with the highest utility. This style of model can be applied to the mode choice problem using socio-economic variables.

The concept of random utility must be used to take account for the fact that the utilities are not known to the analyst with certainty and are therefore treated by the analyst as random variables. The observed inconsistencies in choice behaviour are taken to be a result of observational deficiencies on the part of the analyst.

Four distinct sources of randomness are listed (Ben-Akiva & Lerman):

1. unobserved attributes,
2. unobserved taste variations,
3. measurement errors and imperfect information, and
4. instrumental (or proxy) variables.

The random utility of an alternative can be expressed as a sum of observable and unobservable components of the total utilities. Assuming independently and identically distributed (IID) random utilities, this results in a simple scalable model. Requiring the components to be IID means that the alternatives should also be independent of each other.

The utility for each alternative is contrasted with those of alternative options and converted into a probability value. These probability values range from 0 to 1 and are

often modelled using a logit[18] formulation. The multinomial logit model is derived using this random utility principal and is considered to be the simplest and most popular discrete choice model (Ortúzar and Willumsen, 1994).

In principle the utility function allows any number of explanatory variables. The number of variables in generalised cost functions in conventional models is generally limited. The demand models based on the utility function allow for a more flexible representation of different policies (Ortúzar and Willumsen, 1994). It is necessary to decide which variables are required in the model by checking each variable individually to see if it adds 'explanatory power' to the model. According to Ortúzar and Willumsen (1994) two types of variables exist:

- generic, is common to each alternative, and
- specific, requires a specific coefficient to make it relevant to that alternative.

Some specific variables are not included at all in a particular alternative (i.e. coefficient is 0). The authors point out that it is often difficult to decide in which alternatives the variable should appear. Entering variables in different ways usually produces different results and the only way to reach a satisfactory decision is through trial and error.

The Hierarchical Logit Model addresses a key problem that occurs with multinomial logit formulations – alternatives that are not independent of each other. The principal problem with alternatives not being independent of each other is that some alternatives will be more similar to each other than to others. This is illustrated in Figure 4.7 by an example based on the choice process used in the Dublin transportation model (see chapter 3). The bus and rail are similar, but both are very different from the car alternative. In order to escape this inconsistency all similar alternatives are grouped

[18] Logit models were introduced in Chapter 3.

together in a hierarchy or nest. Each nest is represented by a composite alternative. Bus and DART (rail) are grouped together and the primary choice is made between car and public transport.

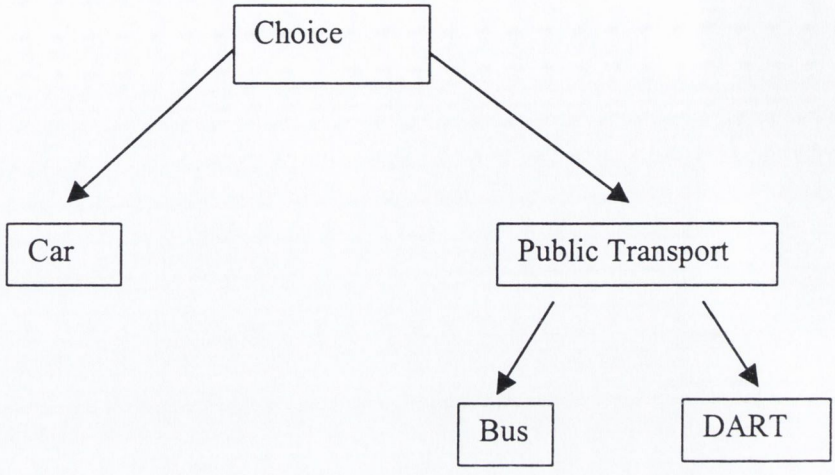

Figure 4.7: Choice Hierarchy.

The choice between car and public transport requires an average generalised cost to be formulated that combines the rail and bus. This means that where rail is the best option it may get omitted at the top level choice between car and public transport as its full benefits are not evident in the choice.

According to Ortúzar and Willumsen (1994) since disaggregate demand models model individual behaviour they are more likely to be transferable to different locations.

4.5 Neural Networks in transport applications

Neural networks have been used in modal split problems before. Reggiani and Tritapepe (1998) undertook a study in Milan of the choice between road and rail travel. The motive for the work was to compare the use of a neural network with a logit model. Both models were constructed as aggregate models with each of the 224 municipalities taken as a population segment. The output of the models is therefore the total number of rail and road travellers from each municipality. The authors conclude at the end of their study that the neural network performs better than the logit model.

Reggiani and Tritapepe (1998) used generalised cost inputs broken down into three components for each of the two modes as follows:

- distance cost,
- time cost, and
- ticket/toll cost.

The neural network used therefore had six inputs but the authors do conclude that using more inputs would give a better estimation of the mode choice. The network used had one hidden layer, and used the 'generalised delta rule' for learning. The network parameters used were:

- $\eta = 0.2$,
- $\alpha = 0.8$.

The neural network avoids the complications associated with the IIA (independence of irrelevant alternatives) property. For all practical purposes the neural network learns only the information supplied by the data and so model assumptions made for logit models are not required. The neural network can capture underlying factors such as differences in tastes.

Shmueli, Salomon and Shefer (1998) conclude from a review of research, that there is a consistency of choice by transport researchers as to the key socio-economic and demographic variables (SED) to have a bearing on 'specific travel related behaviour'. They came up with an input list for a neural network that was quantifying the number of daily trips made for different purposes, work, leisure and maintenance. The input list was as follows:

- number of persons per household,
- number of working adults in household,
- presence of children of various ages,

- proportion of household income earned by male or female head of household,
- household annual income,
- automobile ownership,
- educational level,
- occupation,
- employment status,
- distance to work,
- mode of travel,
- departure time to work.

The authors have identified these inputs as having an impact on the trip making characteristics of the individuals. It is worth categorising these inputs as they will be helpful in identifying the inputs required for the mode choice model. These inputs can be categorised as follows:

- adults and children in household,
- personal information → income, education level, occupation and employment status
- car ownership,
- trip characteristics → distance, mode and departure time,

Shmueli et al. (1998) make the following conclusions:

- the neural network was able to learn and predict travel behaviour,
- it was not possible to interpret the internal relationships set up in the network and so this limits the analysis of how individual inputs impact on the outcome,

- if the network is over-trained so that it is very accurate on the training data then its predictive powers will be reduced as it has learned 'noise' and is less able to generalise.

4.6 Development of neural network for mode choice

It was decided to develop a pilot study so that the model could be tested in a simplified version. In order to reduce the number of inputs required it was decided to target the academics in Trinity College Dublin. All of the people being surveyed were working in Trinity and so had the same trip destination. It was proposed to mail the whole staff but unfortunately this was against college policy and so it was only possible to place a notice on the college homepage noticeboard. The survey and explanatory letter are in Appendix 1.

The survey was developed so as to provide information for the inputs that were deemed to be necessary for a mode choice model. The information sought in the questions can therefore be summarised by the following:

- Mode used to travel to work,
- Mode used to reach public transport stop:– walk/cycle/drive/lift,
- Car availability,
- Car parking availability,
- Travel time for each mode (door-to-door),
- Weather,
- Time of arrival at work,
- Distance to work,
- Mode preference,

- Marital Status,
- Age,
- Number of Children by age category,
- Postal Code.

Information was taken on mode for each day of the previous week to see did people vary the mode they travelled by during a typical week. It was assumed that an average day would be selected which would be one of Tuesday, Wednesday or Thursday. Fifty three questionnaires were returned and the data was input into a database. Due to the small quantity of data, the network developed was not expected to give an accurate indication of the performance of neural networks as mode choice models. What it did provide though was a test bed for ancillary code required and the choice of how the inputs should be presented to the model.

The necessary ancillary code required for presenting the data to the neural network was developed. This code is an early version of that used in the actual docklands case study and so it will be explained in the next chapter. One point worth mentioning now is that it is necessary to shuffle the inputs before each iteration so that the model's learning isn't biased. An explanation of how this is achieved is found in Appendix 2.

The first version of the model consisted of a binary (either '0' or '1') system of 139 inputs as follows:

- Origin → City/Suburban/Country
- Distance between origin and destination in categories:- < 1km, 1 - 2km, 3 - 4km, 5 - 9km, 10 - 19km, 20 - 39km, 40 - 80km, > 80km
- Marital status:- Married/Single/Separated/Widowed
- Sex:- Male/Female

- Age Categories:- <25,25-34, 35-44, 45-54, 55-64, >65
- Children in Household:- children < 4, Primary School, Secondary School
- Mode preference:- Car, DART, Bus, Cycle, Walk
- More than 5 minutes walk required to reach DART/Bus
- Travel Time by mode in minutes for both peak and off-peak: 0 - 4, 5 - 9, 10 - 14, 15 - 19, 20 - 29, 30 - 44, 45 - 60, 60 - 89, 90 - 119 and 120 +.
- Car Availability
- Parking availability
- Arrival time:- < 07:30/07:30 – 08:30/08:30 – 09:30/>09:30

The data is split randomly 60/40 between a training set and test set. This further reduced the quantity of data available for training – 32 data sets for training and 21 for testing. The 139 input system would appear to be an accurate means of inputting this data but due to the small data set (and possibly in the case of all data sets) the inputs tend to lack significance in the training process. This means that during testing the network may not detect the significance of changes in some of the parameters due to the high number of parameters. The motivation for developing the second version of this model was therefore to significantly reduce the number of input nodes in the input layer and hence the number of inputs in each data set.

The number of inputs was reduced by taking the travel time inputs and reducing them to one input for each time period. It is not possible to use a standard time scale from 0 up to the longest trip, which was 120 minutes, because with reference to the sigmoid transfer function no difference in output would be experienced for trips above 10 minutes. It was decided that the travel time inputs would have to be scaled down. Since a number of the inputs are in boolean form it was decided to scale the input into the range 0 – 1.

Maren et al. (1990) suggests that where the range of values for a particular input is large than the logarithm of the variable should probably be used. Using a log scale would give greater significance to the relative time differences for the shorter travel times. The log base was chosen as 120, which is the maximum observed travel time in minutes, resulting in inputs ranging from 0 to 1. The distance categories were also replaced with a log scale input with a base of 80, which is the maximum observed travel distance in km.

A test run was then completed with 37 inputs. It was also decided to leave out the off-peak travel times as they would not have direct bearing on the majority of trips. The 37 inputs are as follows:

City Origin, Suburban Origin, Country Origin,

Distance,

Car Time, DART Time, Bus Time, Cycle Time, Walk Time,

Married, Single, Separated, Widow,

Male, Female,

Under 25 years, 25 – 34 years, 35 – 44 years, 45 – 54 years, 55 – 64 years, Over 65 years,

Children under 4 years, Children at primary school, Children at secondary school,

Prefer Car, Prefer DART, Prefer Bus, Prefer Cycle, Prefer Walk,

DART transfer, Bus transfer,

Car available, Car parking available.

This run was tested over a range of 3 – 6 layers and a range of number of middle nodes. Table 4.1 shows the average number of good outputs, over 5 runs for each

configuration, for the different numbers of layers. The 3-layer network generated on average 11.2 good outputs compared with 9.8, 9.0 and 9.0 for the networks with a greater number of layers. This points to a likelihood that a 3-layer network will be a better network for handling unseen data and predicting correct outcomes.

No of Layers	*Good Outputs*
3	11.2
4	9.8
5	9.0
6	9.0

Table 4.1: Average number of good outputs

Table 4.2 shows some more details of the model run on the 3-layer network. The model was run 5 times for each middle layer configuration. The results presented in each row of Table 4.2 represent the average over these 5 runs.

The key result to note is that the configuration with 37 middle nodes (same number as input nodes) produces the best results. A number of the configurations produce 12 good outcomes but the 37 middle node configuration has by far the smallest standard deviation (0.55) for the 5 runs. It also takes the smallest number of iterations, at 23, for the network to converge. The general trend of the error term is to decrease as the number of middle layer nodes increases. This, and the reduction in iterations trend, would support the theory put forward in the earlier sections, that adding middle layer nodes increases the ability of the network to learn the training set but after some point it begins to lose its ability to generalise. Since the best prediction occurs when the model has the same number of nodes in the input and middle layers then this would appear to be a good starting configuration for any neural network.

The mode preference inputs were then removed, creating a 32 input version. Then results of this network are shown in Table 4.3. This resulted in drastically reduced predictive powers with a large increase in iterations required before the network was

trained. For the 32 node middle layer version only 5 outputs were successfully predicted and it took 116 iterations to train.

Middle Nodes	*Iterations*	*Total Error*	*Good*	*SD*
7	33	1.31	10	0.84
11	33	1.09	11	1.67
15	26	1.27	10	1.10
19	26	1.18	12	1.14
22	26	1.15	11	1.95
26	24	1.07	11	1.14
30	23	1.01	12	1.30
33	49	0.60	12	2.28
37	23	0.96	12	0.55
41	28	0.77	11	1.22
44	33	0.69	11	1.14

Table 4.2: Average outcomes for the 3-layer network

Layers	*Middle Nodes*	*Iterations*	*Total Error*	*Good*	*SD*
3	6	167	0.74	4	1.304
3	10	145	0.72	5	2.000
3	13	123	0.77	4	0.894
3	16	138	0.60	4	1.517
3	19	377	0.42	5	1.446
3	22	535	0.19	4	0.548
3	26	269	0.35	4	1.140
3	29	114	0.60	5	0.447
3	32	116	0.53	5	1.000
3	35	319	0.35	4	0.548
3	38	525	0.21	5	0.707

Table 4.3: Average Outcomes for 32-Input Network.

It was felt that no further tests runs of this pilot version would provide any insightful results that could be applied to the docklands case study. The following conclusions will be applied to the case study version:

- Explanatory information should be presented in as few variables as possible,
- 3-layer network with the number of middle layer nodes equaling the number of input nodes was the best performing network which provides a starting configuration for the case study network,
- All input variables should be in the range 0 – 1 and a log scale should be considered for distance and time variables.

4.7 Summary and Discussion

As stated at the start of this chapter the motivation for this work was to develop a fair and efficient disaggregate mode choice model. The key being to model public transport on an equal basis with car traffic. The basic unit of such a model would be each individual trip maker rather than a vehicle. Such a formulation also has the potential to cater fully for walking and cycling.

The theory behind backpropagation neural networks was explained. The fundamentally unique part of this type of model is that the network learns the relationship between the inputs and outputs. The data is repeatedly presented to the network in random order with errors being propagated back through the network to adjust the weights. It was also established that neural networks are ideally suited to be programmed using object oriented programming. Classes can be formulated for the building blocks of the network – nodes and links – and then extra features can be added by creating child classes. The key strengths of neural networks were identified as being:

- Decision process is modelled through a learning process on surveyed data,

- Networks have been shown to have the ability to generalise and make decisions when presented with new data,
- A large number of explanatory variables can be used,
- Data is presented to network in disaggregate form and so can fully represent each trip maker and their trip.

A couple of weaknesses have been identified as:

- It is not possible to analyse the internal relationships of the network and so it is not possible to discover directly how an individual input actually impacts on the outcome,
- The network can be overtrained and so lose its capability to predict outcomes from a new data source.

The impact of different network configurations and different values for the network parameters were examined and their influence on the training and predictive powers of the network noted. In general additional middle layer nodes will aid the training of a network but may reduce its ability to detect the patterns in the data so that it can make the necessary decisions when predicting outcomes on new data. The network parameters, learning rate, η, and momentum, α, determine by how much the weights in the network should be changed after each data item is presented to the network.

To place the development of the neural network mode choice model in context some mode choice model formulations were reviewed. It was seen that the majority, including Dublin, used data in the form of aggregate population segments. The decision process in such models is based on a generalised cost formulation. Some disaggregate models were investigated and it was found that these models allowed a greater number of explanatory variables compared to that used in the generalised cost function. It was also concluded that disaggregate models can be more easily transferred to new locations. A key problem with the logit model (a form of disaggregate mode choice model) is that the options can not be similar. This requires a hierarchical

decision process to take place and this results in the public transport choice process not being adequately modelled.

Two examples were shown where neural networks had been used in transport applications. In both cases the neural network was shown to be able to adequately model the travel behaviour. It was also shown that the neural network does not require some of the logit model assumptions such as requiring the alternatives to be independent of each other. It can also cater for underlying factors like differences in tastes.

The pilot study developed on Trinity College destinations showed how a neural network could model some of the mode choice decisions made. Due to a lack of enough data items the performance of the model was inadequate at predicting mode outcomes but the following points were learned in the process:

- Where data is collected in categories the data should be condensed into one input for improved training performance,
- A log scale should be considered for time and distance inputs,
- Starting network configuration of 3 layers and the number of middle layer nodes to be equal to the number of input layer nodes.

Chapter 5

Development of a Neural Network Mode Choice Model

5.1 Introduction

The first part of this chapter gives a description of the study area and its demographics. Additional detailed information is required on travel in the study area so that individual information can be input into the mode choice model. The approach used to collect this information will be described. Subsequently the methodologies required to interface this data with the neural network are outlined.

The final sections of this chapter deal with the performance of the neural network mode choice model. A series of runs are completed on test data to gauge how different combinations of inputs and different network configurations perform. The aim of this is to decide on a particular version and configuration to test on the full study area.

5.2 Study Area

The study area is based on the southern docklands as set out by the DDDA in their Master Plan (DDDA, 1997). Figure 5.1 shows the boundaries of the study area. The northern docklands were excluded for two key reasons:

- Further development of the north docklands is heavily dependent on the large CIE owned site. Due to the ongoing planning wrangling over the development of this site it was decided that it would be extremely difficult to accurately forecast an outcome.

- Options for public transport improvements in the area would appear to be fairly straightforward – light rail extension on or near the Mayor Street alignment terminating near the Point Depot.

There is potential for developing new public transport in the southern docklands. The mode choice model will enable a comparison of the transport benefits of different route options to be made. Development of the area is also more predictable due to the following:

- Pivotal development area of the southern docklands is the Grand Canal Docks area which has its own Action Plan (DDDA, 1999) arising out of the Master Plan (DDDA, 1997).

- Key development site in the Grand Canal Docks Area is in the ownership of the DDDA and so will be developed according to plans.

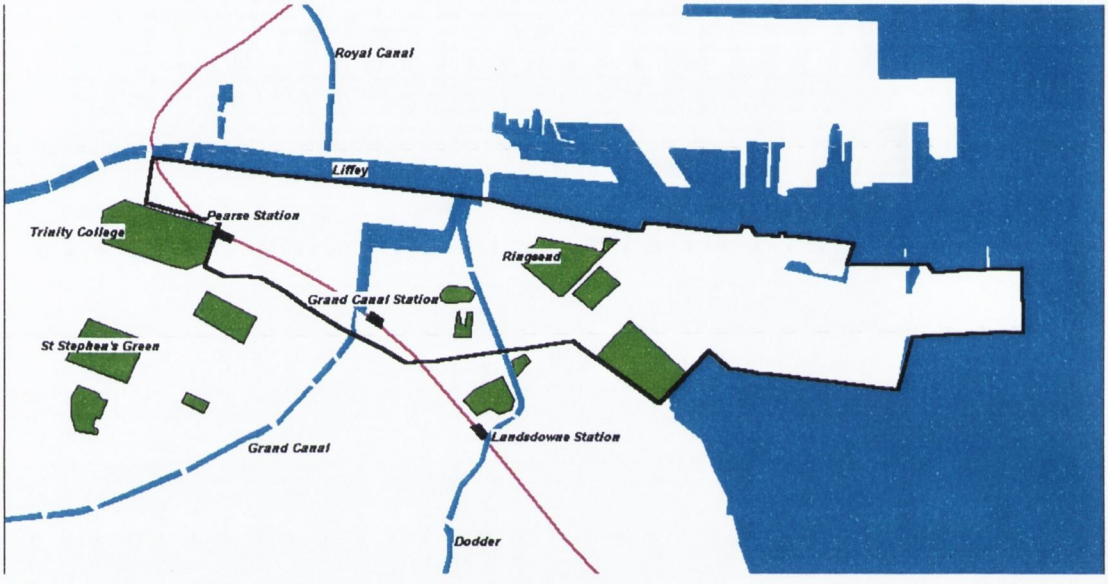

Figure 5.1: Southern Docklands study area.

The Docklands area is surrounded by some of the most important public transport elements in the city. Many of the initial developments in the Docklands area, including the IFSC in the Custom House Docks Area, have taken place along these important transport corridors.

The high quality transport infrastructure near or in the Docklands area includes:

- DART along the northern and southern edges,

- Urban rail service from west Dublin terminating in Connolly Station,

- Newly upgraded Malahide Quality Bus Corridor.

- These services though have little impact on the southern Docklands area. The public transport routes that pass through or near the study area are located graphically in Figure 5.2.

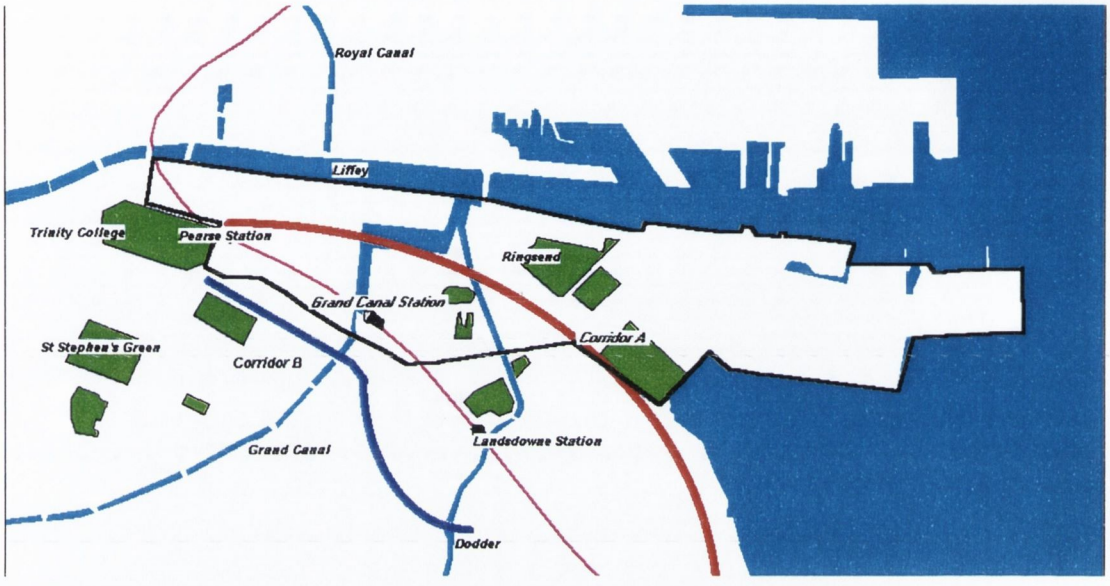

Figure 5.2: Public transport Corridors

There are currently only two DART stations within or near the area, Pearse Station and Lansdowne Station (see Figure 5.2). A new station called Grand Canal Dock was being constructed whilst the survey work was being undertaken. The station which is located in the centre of the study area opened on Monday, January 29, 2001. This has improved access to the DART for residents of the area. Currently the DART does not provide a useful service to the city centre for residents. In many cases it would be quicker to walk to the city centre than walk to a DART station and travel by train. For residents of the area the principal use of the DART is for reaching suburban destinations along the DART line. The frequency of service provided by the DART between 07:00 and 10:00 is shown in Table 5.1 to be approximately every 10 minutes.

There are two distinct bus corridors in the area which are shown in Figure 5.2 and labeled as Corridor A and Corridor B. Numbers 1, 2 and 3 run on the corridor A while numbers 5, 7, 7A, 8, 45, 46, 63 and 84 run on corridor B. Table 5.1 shows the service frequency for each route number. Bus nos 2 and 3 both run along the same route

between Sandymount and Parnell Square and so the frequency along this section is greater. Similarly the first section of Bus Corridor B has quite a high frequency of buses on it.

	Destination	*Average Frequency 07:00 – 10:00*
DART	Howth/Bray	10 minutes
Bus Nos		
1	Poolbeg	1 bus out in the morning
2	Parnell Square/Sandymount	17 minutes
3	Whitehall/Sandymount	18 minutes
5	City Centre/Sandyford	3 buses out in the morning
7	City Centre/Loughlinstown	14 minutes
7A	City Centre/Mackintosh Park	3 buses out in the morning
8	City Centre/Dalkey	25 minutes
45	City Centre/Bray	20 minutes
46	City Centre/Shankhill	1 bus
63	Kilternan	1 bus
84	Bray	2 buses

Table 5.1: Frequency of Direct Public Transport Services from Study Area

Table 5.1 shows the frequency of service to different destinations. Corridor B has a frequency of less than 5 minutes as far as the Dodder river. From then on the various routes have different frequencies for different destinations. It is noted that some of the routes such as 5, 7A, 46, 63 and 84 have very poor frequencies but serve particular destinations.

A catchment area is determined around each public transport stop. Research has shown that people will tend to walk up to 500m (approximately 5 minutes) to a bus stop and

up to 1,000m to a rail station. Catchment areas around these bus stops are mapped out at 500m contours along possible walking routes. Figure 5.3 shows the catchment areas for the two bus corridors in the study area. The catchment areas overlap considerably and so the residents of the area in corridor A and B can chose which corridor suits their journey best.

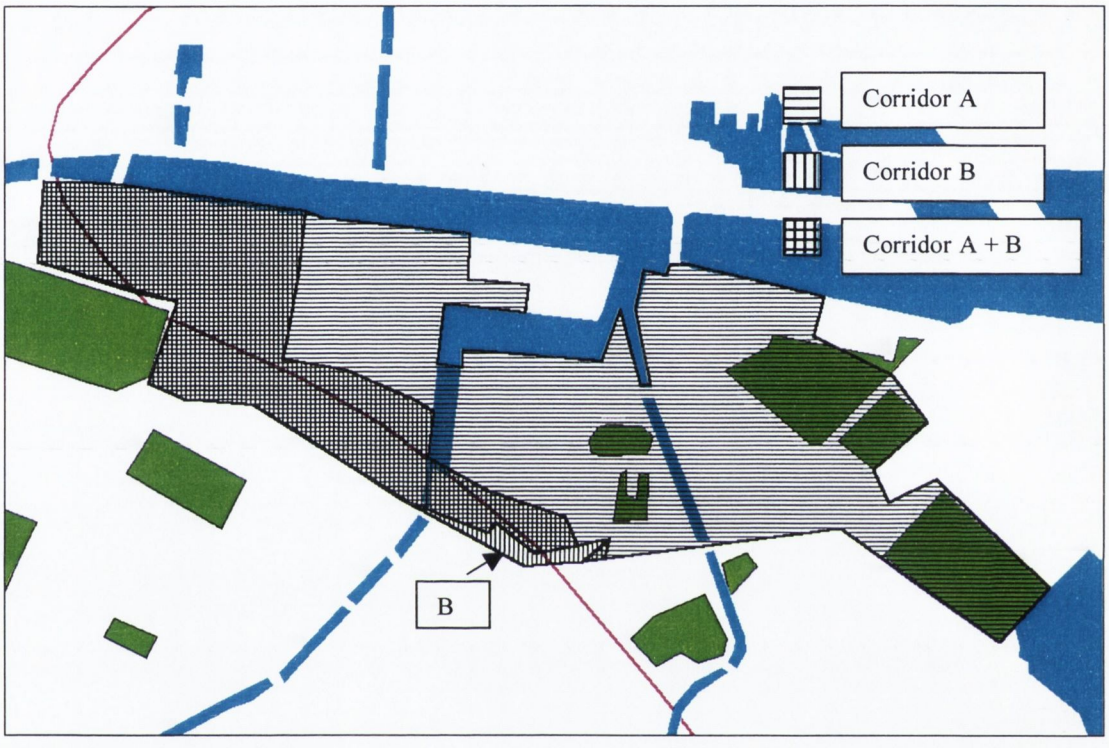

Figure 5.3: Bus Catchments

Looking at Figure 5.3 it can be seen that the catchment areas cover a large proportion of the study area. A key factor for (see section 2.2) reducing car use and achieving high levels of public transport use was urban density. It is therefore worthwhile investigating the density of the catchment areas. The densities for the two bus corridors are as follows:

- Corridor A: 60 pph,
- Corridor B: 68 pph.

This means that the density of the two corridors is above the threshold level considered necessary to reduce car use and encourage public transport use.

Catchment areas for the DART stations are mapped out at 500m and 1,000m contours and are shown in Figure 5.4. Due to the greater distances between stops the catchment area for the DART is very different from that for the bus. The 500m catchment area is focussed on each stop where as in the case of the bus catchment it is a continuous area.

Grand Canal Street DART station is the only station with the majority of its 500m catchment within the study area. The density of this area is 82 pph, which is considerably higher than the density of the bus catchment.

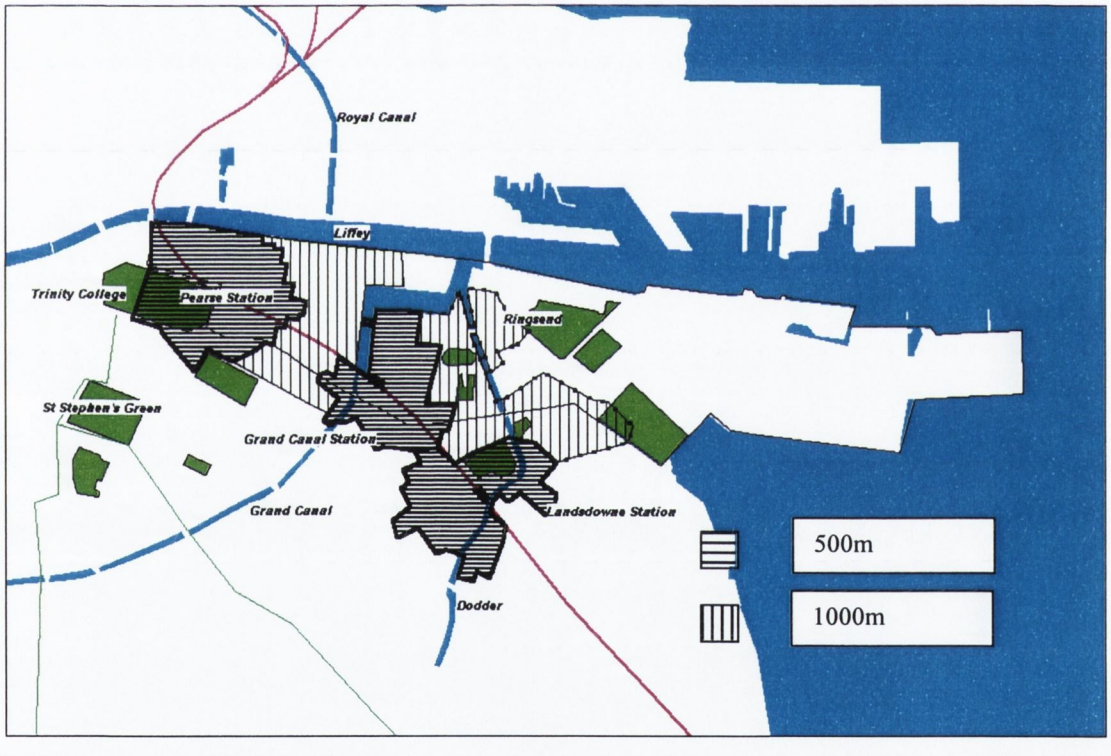

Figure 5.4: DART Catchment

5.3 Current Demographics

It was shown in chapter 4 that the demographics of the Docklands area in Dublin has been changing during the last 10 years. This section will now examine the demographic changes for the southern Docklands study area. The analysis will be

based on the parts of the wards that are within the study area as discussed in chapter 3. The southern dockland wards are shown in Figure 5.5.

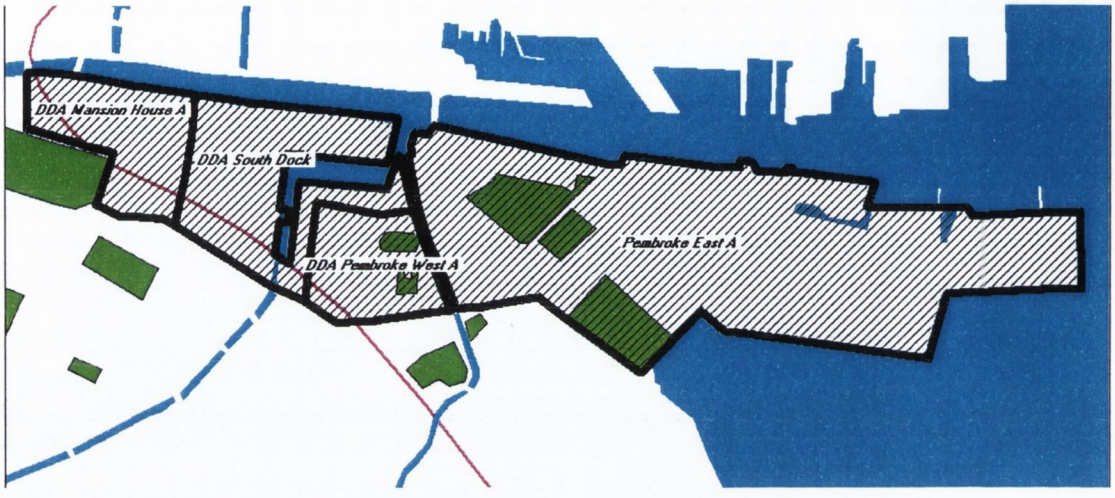

Figure 5.5: South Dockland Wards.

Table 5.2 shows the statistics for the total population in each ward. It is evident that the biggest growth has occurred in DDA South Dock. The figures show a 28% increase between 1991 and 1996 with an additional 359 people moving into the ward. Pembroke East A shows a 2% decrease whilst DDA Mansion House A and DDA Pembroke West A show modest increases of 4% and 7% respectively.

	1991	*1996*	*% Change*
DDA Mansion House A	2409	2511	4%
DDA South Dock	1295	1654	28%
DDA Pembroke West A	1535	1646	7%
125 Pembroke East A	4427	4349	-2%

Table 5.2: Total Population in each ward. (Source: CSO, 1991 & 1996)

Table 5.3 shows the numbers in each age group for each ward in 1996 and the percentage change since 1991. The two wards with the largest overall growth, DDA South Dock and DDA Pembroke West A, experience the greatest percentage growth in the 20 – 64 age category with 54% and 20% respectively. This means that there will be

a significant increase in the number of people seeking to make a peak hour journey to work.

	0 - 19		*20 - 64*		*65+*	
	1996	*%*	*1996*	*%*	*1996*	*%*
DDA Mansion House A	690	4%	1541	6%	281	-6%
DDA South Dock	314	-2%	1147	54%	193	-17%
DDA Pembroke West A	281	-12%	1117	20%	249	-13%
125 Pembroke East A	1214	-11%	2573	1%	562	8%

Table 5.3: Number of persons in each age category in 1996 and the percentage increase or decrease since 1991. (Source: CSO, 1991 & 1996)

Table 5.4 shows the numbers of males and females within the population of each ward. In each of the wards there are more females than males. Overall females make up 53% of the population of the area.

The housing characteristics for the four wards are shown in Table 5.5. It shows that there is a large increase in the number of flat/bedsits in DDA South Dock (90%) and DDA Pembroke West A (101%). The increase in flat/bedsits in DDA South Dock is accompanied by a 22% decrease in the number of conventional houses in the ward.

	Male	*Female*
DDA Mansion House A	1217	1294
DDA South Dock	764	890
DDA Pembroke West A	742	904
125 Pembroke East A	2050	2299
Total (%)	*47%*	*53%*

Table 5.4: Number of persons categorised male and female. (Source: CSO, 1991 & 1996)

The Docklands Authority aim to achieve a target of 8,000 – 11,000 additional residents in the whole Docklands area by 2015 (DDDA, 1997). It is the development trend towards flat/bedsits, which would enable the residential population densities to reach the levels necessary to achieve this goal. This type of development is also very conducive to being serviced by high frequency public transport.

	Conv. House	*%change*	*Flat/bedsit*	*%change*
DDA Mansion House A	144	9%	926	-3%
DDA South Dock	171	-22%	521	90%
DDA Pembroke West A	550	6%	163	101%
Pembroke East A	1048	7%	455	8%
Total	***1913***	***4%***	***2065***	***19%***

Table 5.5: Changes in Principal Housing Types 1991-1996. (Source: CSO, 1991 & 1996)

Table 5.6 shows the participation and unemployment rates for the wards. It is the number of people at work in the area that will give an indication of the demand for travel during the morning peak period. People who are not in active employment outside of the home are assumed to avoid travelling during the morning peak period.

	Participation Rate		*Unemployment Rate*	
	1991	1996	1991	1996
DDA Mansion House A	43.7%	47.8%	36.1%	30.4%
DDA South Dock	52.5%	65.6%	24.6%	13.8%
DDA Pembroke West A	55.0%	60.1%	15.1%	10.8%
125 Pembroke East A	56.3%	57.7%	28.7%	26.6%

Table 5.6: Participation and Unemployment Rates. (Source: CSO, 1991 & 1996)

The participation rate definition is defined from the number of persons at work, plus the number seeking their first job plus the number unemployed divided by the total

population aged 15 years and over. The unemployment rate is the number unemployed plus the number seeking their first job divided by the labour force. DDA South Dock and DDA Pembroke West A both show large improvements in their participation rates and unemployment rates between 1991 – 1996. In contrast Pembroke East A has the highest unemployment rate and shows only a very small improvement during the same period.

Table 5.7 shows the population segments that would not wish to travel during the morning peak period. In Pembroke East A and Pembroke West A 15% of the male population is retired. This is higher than that observed in the other two wards. Interestingly the proportion of retired females is close to 10% in all four of the wards. Unemployment peaks in Pembroke East A at 19% of males and is closely followed by a figure of 18% of males in DDA Mansion House A. The lower unemployment levels in DDA South Dock and DDA Pembroke West A suggest that these areas are more affluent. The proportion of females undertaking home duties is also higher in DDA Mansion House A, 34%, and in Pembroke East A, 32%, whilst the figures in DDA South Dock and DDA Pembroke West A are 16% and 24% respectively.

	DDA MHA		*DDA SD*		*DDA PWA*		*PEA*	
	M	F	M	F	M	F	M	F
Retired (%)	10	9	12	11	15	10	15	10
Unemployed (%)	18	9	12	5	9	4	19	11
Home Duties (%)	0	34	0	16	0	24	0	32
Not Working (%)	5	5	6	2	3	3	6	5
Total	33	56	30	34	27	41	40	58

Table 5.7: Proportions of Population not travelling to work. (Source: CSO, 1991 & 1996)

The level of car ownership in an area is a key determinant of the level of car use. Unfortunately data is not available from the 1996 census on car ownership levels but the 1991 figures for the study area were as follows:

- South Dock → 133 cars per 1000 population,
- Pembroke West A → 214 cars per 1000 population,
- Pembroke East A → 102 cars per 1000 population

These figures are considerably lower than the average in Dublin in 1991, which was 247 cars per 1000 population. As shown in Table 3.5 this has risen dramatically through the '90s and was recorded as 342 cars per 1000 population in 1999. It can be assumed that a large increase in this statistic has occurred in the study area as well.

5.4 Survey Methodology

A questionnaire was complied to collect all the information that had been deemed necessary through the study of literature and subsequently in the pilot study presented in the previous chapter. The questionnaire is presented in Appendix 4. It was desired to request as much information as possible so as to allow flexibility in testing to see what input variables should be used in the construction of the full version of the model.

The questionnaire was sent to 3,559 residential addresses in the South Docklands area in May 2000. Delivery was achieved using An Post's Direct Mail service. This service works by the user selecting the postal routes required for the mail shot and An Post delivers the item to each address with the daily post. In addition it is possible to specify whether you wish to target residential addresses or business addresses or both. For the purpose of this survey it was decided to target only the residential addresses.

Each envelope included the following:

- letter explaining purpose of survey (Appendix 3),
- questionnaire to be filled in by a resident (Appendix 4),
- business reply envelope (postage paid).

A total of 355 replies were received, which is just under 10% of the number sent out. A validation procedure was carried out before the surveys were entered into the custom built database. This procedure was necessary to exclude any responses that were incomplete or irrelevant to the work being undertaken.

21 surveys were returned by people who worked in the target area but were resident outside of the area. It is assumed that there are a small but significant number of addresses that An Post has classified as residential but are in fact work places. These 21 are not included in this analysis as this work is dealing with trips originating from this area. A further 5 survey returns were excluded as the trip recorded was not made in the morning peak. 14 incomplete surveys were received of which 3 were deemed to be sufficiently complete and were included.

318 complete surveys were left after the validation process and were input into a custom built database. As a result the rest of this analysis will be conducted with reference to 318 completed surveys. Table 5.8 shows the return statistics.

Description	*No of Surveys*	*Returns (%)*
Complete	315	89
Incomplete	14	4
Work Places	21	6
Not Morning	5	1
Total	355	100

Table 5.8: Survey Returns

The postal routes selected for delivery were:

- Dublin 4, Routes 3, 4, 5 & 6
- Dublin 2, Routes 29 & 34

These 6 routes are shown in Figure 5.6. It is apparent that they cover much of the study area. The area east of the Dublin 4 Route 6 does not contain any residential areas and

so it was not necessary to survey that area. The area between Dublin 4 Route 5 and Dublin 4 Route 3 comprises mostly of Shelbourne Park Greyhound race track and so it was also omitted from the survey.

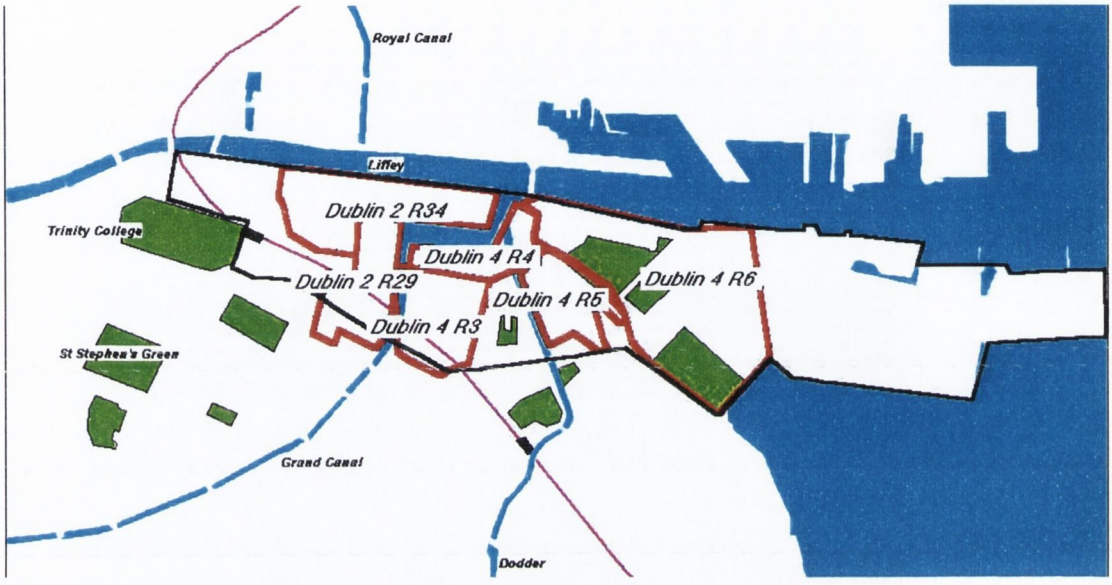

Figure 5.6: Map of delivery routes.

Table 5.9 shows the return proportions by postal route. Checks were made to ensure delivery took place by contacting people known to the author who lived in the target areas. Unfortunately some problems with the Direct Mail service were identified that may have had a bearing on the proportion of returned surveys.

In some of the Charlotte Quay Dock apartments, Dublin 4 Route 4, the surveys were not delivered to individual post boxes but just left in a pile on top. Following correspondence with An Post they said, that the individual had been spoken to and assurance was given that this was an isolated incident. In addition to this matter the surveys in Dublin 4 Route 3 were not delivered until 2 weeks after the specified date. Paradoxically though it is these two postal routes that showed the best rates of return. Route 3 with the highest at over 14% and Route 4 with the next highest at over 10%.

	Residential Addresses	*Returned*	*Returned (%)*
Dublin 4			
Route 3	667	94	14
Route 4	741	77	10
Route 5	600	49	8
Route 6	686	29	4
Dublin 2			
Route 29	280	24	9
Route 34	585	45	8
Total	*3559*	*318*	*9*

Table 5.9: Surveys Returned by Postal Route

5.5 Analysis of Survey Returns

Travel data was collected for each day of the week. This data refers to the person in the household who actually filled out the questionnaire. Table 5.10 shows the way that the mode split varies over the course of a week. Where people travelled by more than one mode, the mode on which they leave the study area is considered to be their primary mode and is recorded as a single mode.

Notably the percentage of people walking is quite high, varying between 37% to almost 43%. The walking standard deviation is also the highest showing that there are large number of people who walk a few days a week and for various reasons choose another mode on other days. Car travel on average is over 37% if you include the people who travel as passengers. Bus and DART combine to give over 12% and DART has the lowest standard deviation of the stated modes. Cycling is also significant with over 9% of the modal split.

	Mon (%)	*Tues (%)*	*Wed (%)*	*Thurs (%)*	*Fri (%)*	*Average (%)*	*Standard Deviation*
Car	36.2	33.0	35.9	37.1	36.8	35.8	1.62
Car Passenger	1.2	0.6	1.6	1.6	2.2	1.5	0.57
DART	3.1	3.5	2.8	2.5	2.8	3.0	0.36
Bus	7.9	9.0	9.4	10.1	9.4	9.2	0.81
Cycle	10.1	9.5	9.4	9.4	8.8	9.4	0.44
Walk	39.9	42.8	39.6	37.4	37.1	39.4	2.28
Other	0.3	0.3	0.0	0.3	0.0	0.2	0.17
Worked at home	1.3	1.3	1.3	1.6	2.8	1.6	0.68

Table 5.10: Modal Split over a Week

With reference to Table 5.10 it is apparent that the average column corresponds closely to the column for Wednesday. As a result mode choice data for Wednesday is chosen to be used as the average day. This means that your typical modal split for the area is as follows:

- Car → 37.5%,
- Public Transport → 12.2%,
- Cycling → 9.4%,
- Walk → 39.6%, and
- Other → 1.3%.

The principal thrust of the future plans for Dublin focuses on car and public transport. These mechanised modes cater for less than 50% of the peak morning trips from this rapidly expanding area that is in close proximity to the city centre. This shows the potential for locating residential and employment generators close to each other.

There are two key determinants of whether car travel is a viable alternative. These are car availability and parking availability. Table 5.11 shows the car availability proportions by ward for the population that travels to work from each ward. The notable trend in Table 5.11 is that the percentage of people with a car available increases with increasing distance away from the city centre. Only 37.2% of the respondents have a car available in Mansion House A whilst almost 80% of respondents have in Pembroke East A.

Ward	*Car Available*
Mansion House A	36 %
South Dock	59 %
Pembroke West A	68 %
Pembroke East A	79 %
Average	63 %

Table 5.11: Car Availability by Ward

Availability of parking close to a person's destination is the second factor that impacts greatly on whether people travel by car or not. Figure 5.6 shows, using a Venn diagram, the number of respondents that fit in the three categories of car availability, parking availability and choosing to drive to work. 195 (63% of the respondents) have a car available and 180 (58%) have parking available. Importantly, only 133 people (43%) have both a car and parking available to them. Of the 108 respondents who drive to work 95 of them have both a car available and free parking available to them. The remaining 13 car drivers have to pay for parking at their destination. This following statistics show the importance of car and parking availability:

- 55% of respondents with a car available, drive to work,
- 71% of respondents with both a car and parking available drive to work.

This shows the significance of having parking available on the mode choice decision. These statistics can also be looked at from another direction. In fact 45% of the people

who had a car available to them didn't travel by car. 29% of people with both a car and parking available to them didn't travel by car.

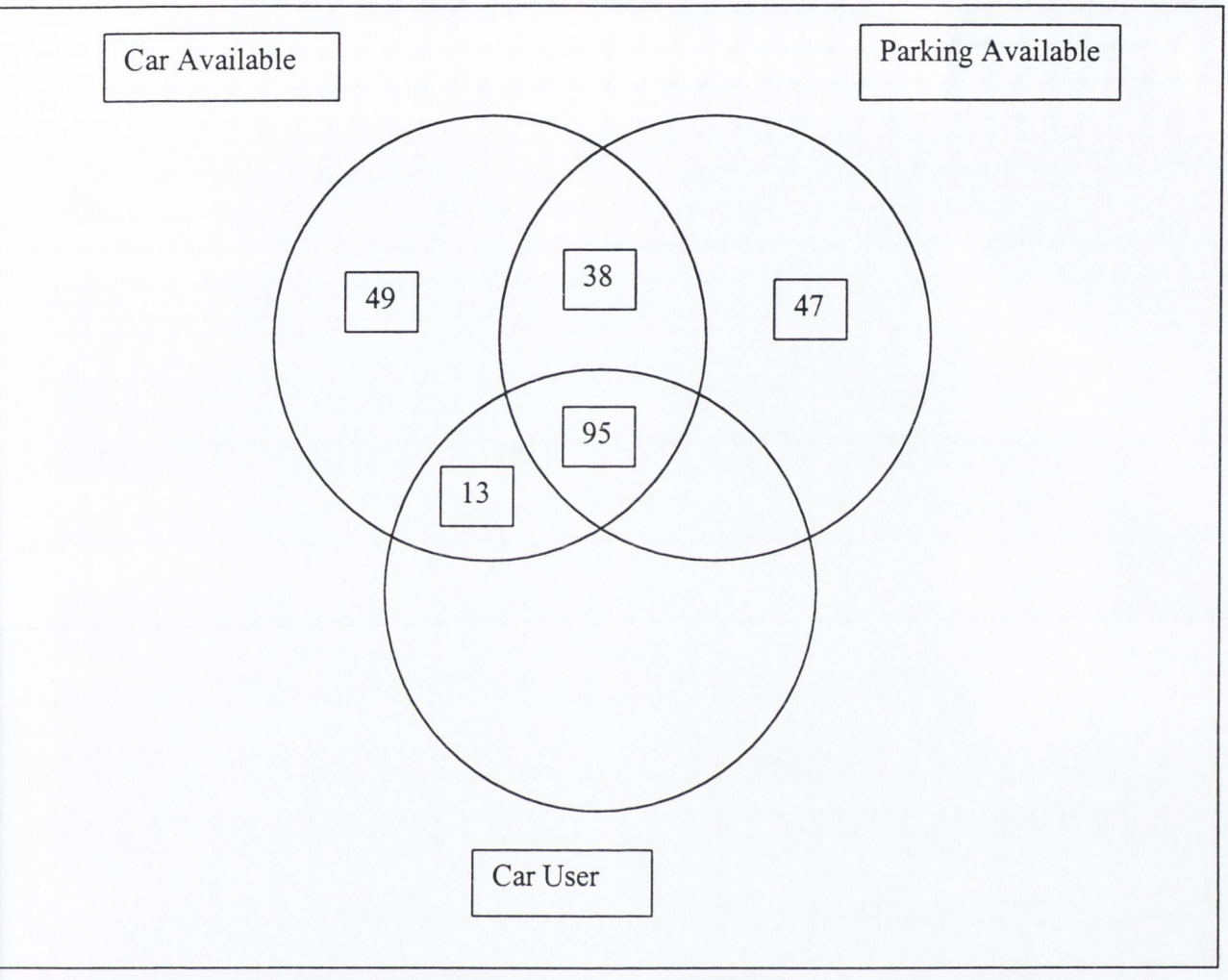

Figure 5.7: Venn Diagram of Car and Parking Availability.

It is important to investigate more closely these people who could have travelled by car but chose to travel by a different mode. Table 5.12 shows the proportion of trips made by alternative modes where there was a car available and where a car and parking was available. A high proportion of cyclists, 48%, have a car available to them and 36% of cyclists have parking available as well. A notable result is that only 28% of the bus users had a car available to them whilst 33% of the DART users had a car available to them. The difference increases when considering car and parking availability with a figure of 33% for DART and only 14% for bus. This points to the theory that rail based public transport has a greater potential for attracting car users.

Mode	*Car Available*	*Car Available + Parking Available*
DART	33%	33%
Bus	28%	14%
Cycle	48%	36%
Walk	44%	11%

Table 5.12: Car Availability by Mode Chosen

Figure 5.8 shows the distribution of observed trips by strategic zone. It can be seen clearly that a large proportion of trips from the study area are focused on the central and south-east parts of the city centre. In fact 55% of the respondents have destinations within the canal ring.

Figure 5.9 shows the distribution of trips from the study area within the canal ring. It can be seen that more of the destinations are in the south-east central part of the city. This means that there will be a large quantity of people travelling quite small distances to work. Figure 5.10 shows the trip length distribution for the observed trips. It can be seen that a large proportion of the trips are under 4 km and in fact the graph peaks on the 1 – 2 km category. Another way of showing the quantity of short trips is to express them as percentages of the total number of trips as follows:

- 39% of trips are under 2 km,
- 67% of trips are under 4 km.

This large proportion of short trips shows the benefits of locating residential areas in close proximity to employment generators.

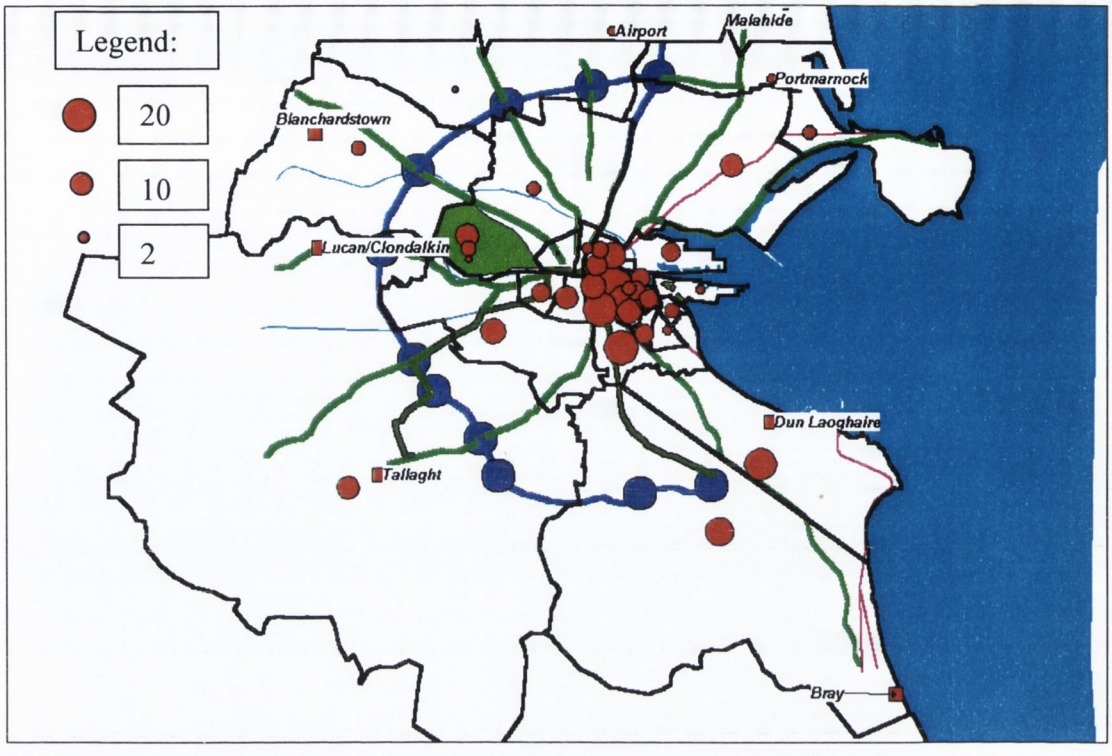

Figure 5.8: Destination Distribution by Strategic Zone (number of trips).

Figure 5.9: City Centre Destination Distribution.

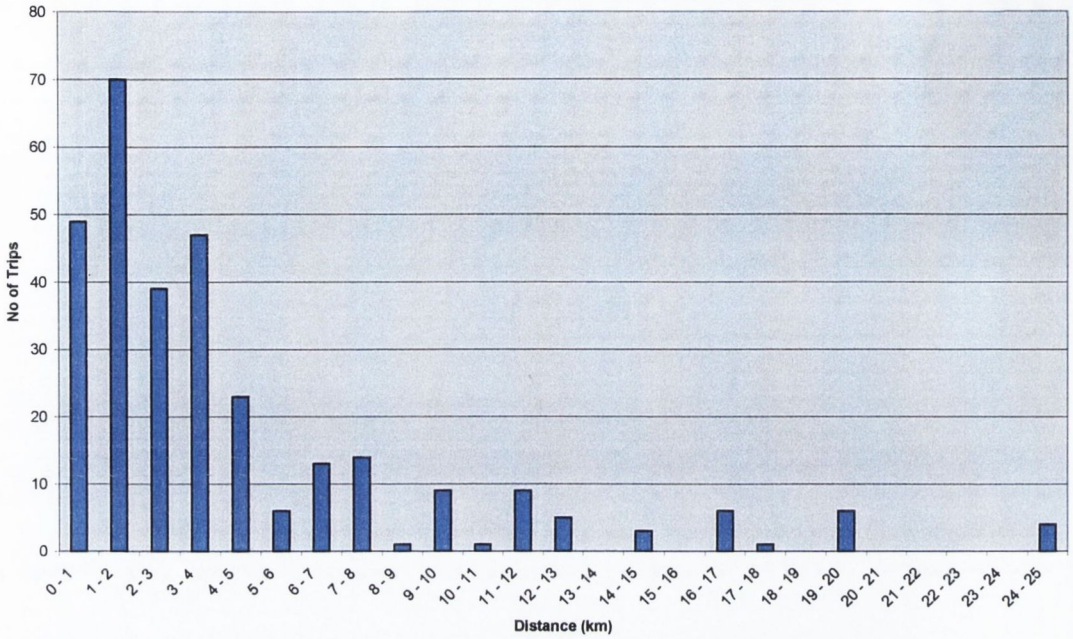

Figure 5.10: Distance Distribution

Figure 5.11 shows the age profile of respondents in each ward. Figure 5.12 shows the age profile of the wards as recorded by the census in 1996. The under 25 and over 65 categories differ greatly between the two figures. The low level of respondents from the under 25 category occurs because in most cases a parent would have filled in the survey. A possible explanation for the second discrepancy is that people over 65 did not reply to the survey as they saw that the survey was targeting a morning peak period trip to work.

The other age categories are grouped in 20 year groupings for comparison with the census data. Comparing the two figures it appears that the 25 – 44 age group has a higher rate of response than the 45 – 64 age group. Since 2000 survey data is being compared with 1996 census data, it is possible that part of this difference can be accounted for due to this population segment continuing to grow as it did between 1991 and 1996 (see figure 3.14).

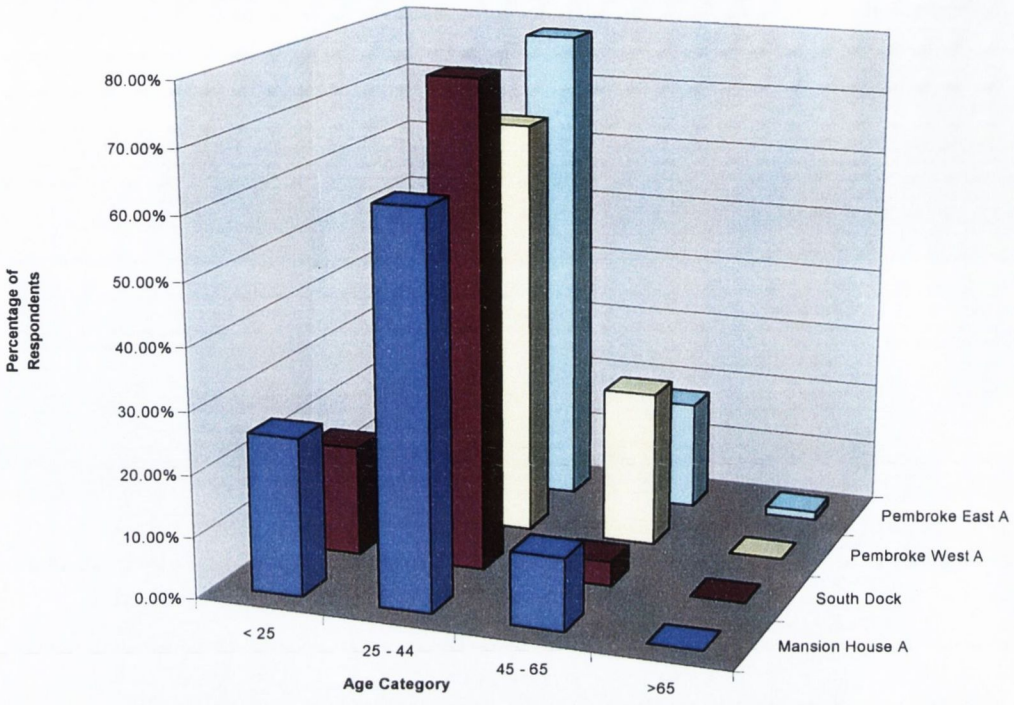

Figure 5.11: Age Distribution of Respondents (Source: Survey data)

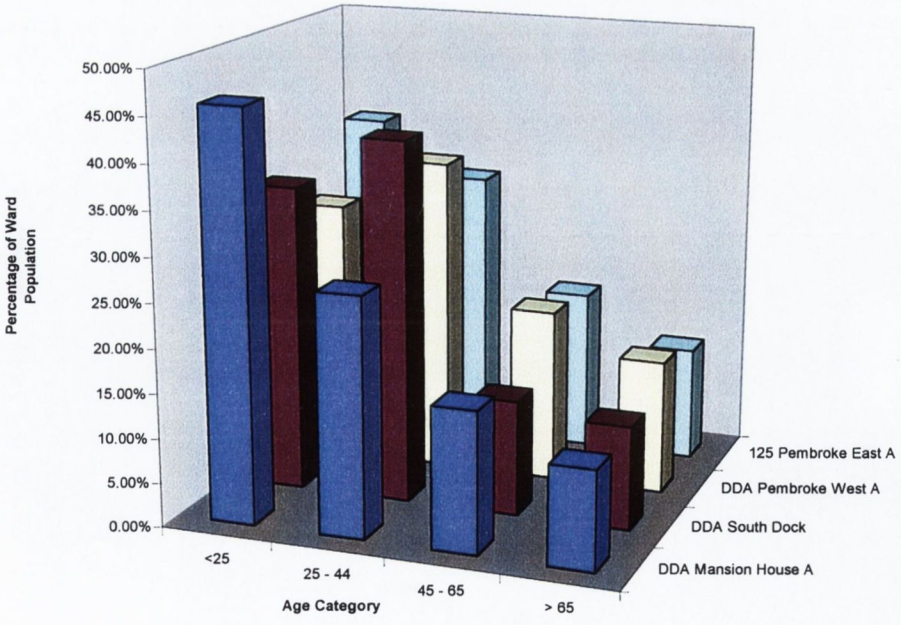

Figure 5.12: Age Distribution in Wards (Source: CSO, 1996)

The two figures confirm the young age profile of South Dock. In both there is a large difference in the percentage of people between the 25 – 44 age category and the 45 – 65 age category.

Overall 45% of the respondents were male and 55% female. This corresponds to the overall statistics for the area presented in section 5.5 where it was shown 47% were male and 53% were female.

Table 5.13 shows the number of houses and flats in each ward's responses. The notable points are that there are more flats than houses in Mansion House A and South Dock and the more houses than flats in Pembroke West A and Pembroke East A. This is the same trend that can be observed in Table 5.5, which was compiled from census data.

	House	*Flat*
Mansion House A	2	41
South Dock	31	70
Pembroke West A	75	19
Pembroke East A	63	17

Table 5.13: Number of Houses and Flats by Ward in Responses

Table 5.14 shows the average number of people per residence for each house type in each ward. It shows that there is a higher occupancy in the houses than in the flats. The highest house occupancy is found in Pembroke East A but interestingly a marginally lower flat occupancy rate is found in this ward as well.

Accompanying the lower occupancy of apartment living is a lower proportion of children living in apartments when compared to houses. The proportions of adults in the two distinct house types are as follows:

- House: 70%
- Apartment: 94%

	Conv. House	*Flat*
Mansion House A	2.5	2.2
South Dock	2.2	2.0
Pembroke West A	2.4	2.0
Pembroke East A	3.1	1.9

Table 5.14: Occupancy of Household

Figure 5.13 shows the salary profile of the respondents in the study area. It is evident that Mansion House A has the highest proportion of people on a very low income. In fact over 25% of the respondents in this ward earn less than £10,000 per annum. Pembroke West A and Pembroke East A both show a more even profile than either of the other two wards. The two Pembroke wards and South Dock all show a significant peak in the £30-50,000 category, but of course this is partly due to the fact that this category has a range of £20,000 pounds rather than £5,000. South Dock has the largest number of people on a high salary with almost 40% on £30,000 or more.

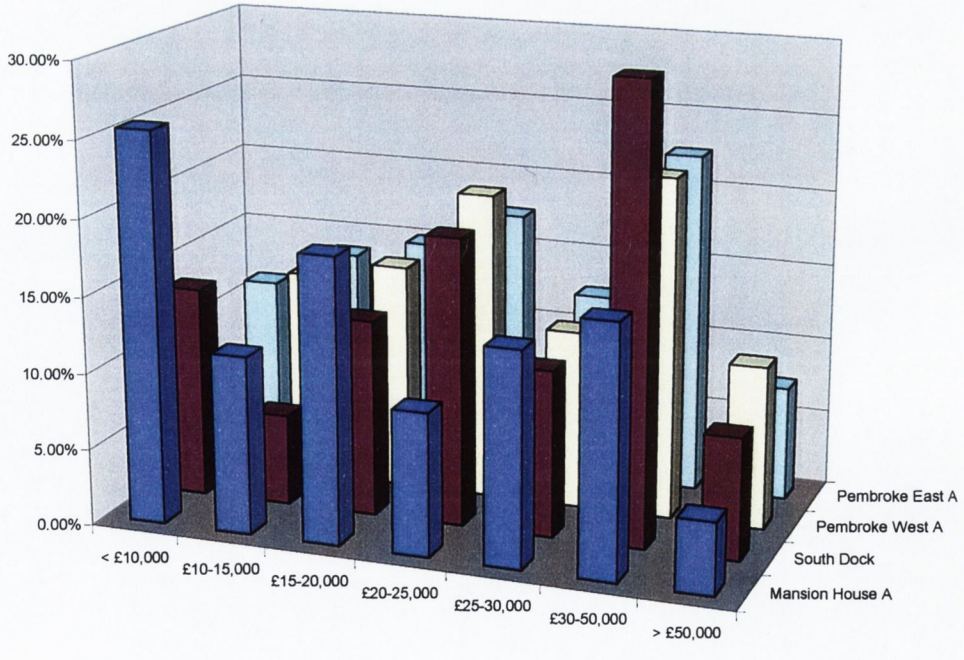

Figure 5.13: Salary Profile of Respondents.

The demographic analysis by its similarity to that presented from CSO data shows that the survey is representative of the study area. The most significant finding in the survey was the number of people that walk to work from the study area. Over 39% walk and when combined with cycling these two modes account for almost 50% of the trip origins in the study area. As mentioned earlier this is not really mentioned or dealt with in great detail in any of the plans or reports for Dublin. It shows with the continuing expansion of the area in a mixed used form that there is great potential for maintaining or increasing the percentage of people walking or cycling to work in the mornings.

5.6 GIS Data compilation

All of the data collected refers to a trip that has an origin in the study area and a destination somewhere in the GDA. A map of the GDA is created which contains all the information associated with such trips. Such a map is known as a geographic information system (GIS).

GIS's are characterised by the fact that the information recorded has a spatial context and can be queried by the user so as to gain specific outputs. The information can be split up into categories or themes which are represented as layers of information (Martin, 1996). These layers are all associated with the same background general map and the information stored relates to a specific location. A GIS query might entail the merging of two or more layers of information to find a particular commonality.

The GIS map compiled for this work comprises the GDA with particular focus on the Dockland area. Data is contained in a large number of layers and in summary includes the following information:

- Ward boundaries,
- Residential area categorised by apartment or street name,
- Public transport routes,

- Origins,
- Destinations,

The Origin and Destination data can be queried with the rest of the data in the GIS. The query is then imported into a conventional database program. A table can then be compiled from which the mode choice model will extract all the necessary inputs.

There are three different systems of ward boundaries presented on the map. First of all there is the basic ward system of DED areas. The ESRI when compiling data for the Docklands Area used partial wards so that their data would only refer to land contained within the Docklands Area. These partial wards are prefixed with DDA whenever they are being referred to. In addition the DTO has subdivided the city centre wards for more accurate traffic modelling.

The residential areas in the docklands are categorised by street name or where applicable apartment name. Figure 5.14 shows the residence groupings that were used in the study area. A symbol is located on the map to locate each particular residential area. Some of the smaller roads have been grouped into one heading:

- Stella Gardens refers to the whole estate,
- "Doris" groups the following streets: Gerald, Howard, Hope, Joy, Penrose, Doris, Ormeau, Somerset.

The public transport routes that pass through or near the Docklands are located graphically in another map layer. The frequency of service of buses at each particular bus stop in the area is held in a table linked to the map. In addition the frequency of service to a particular destination is also recorded. A trip from a certain street is associated geographically with the symbol for that street on the map. This means that the available transport services can be determined for every trip.

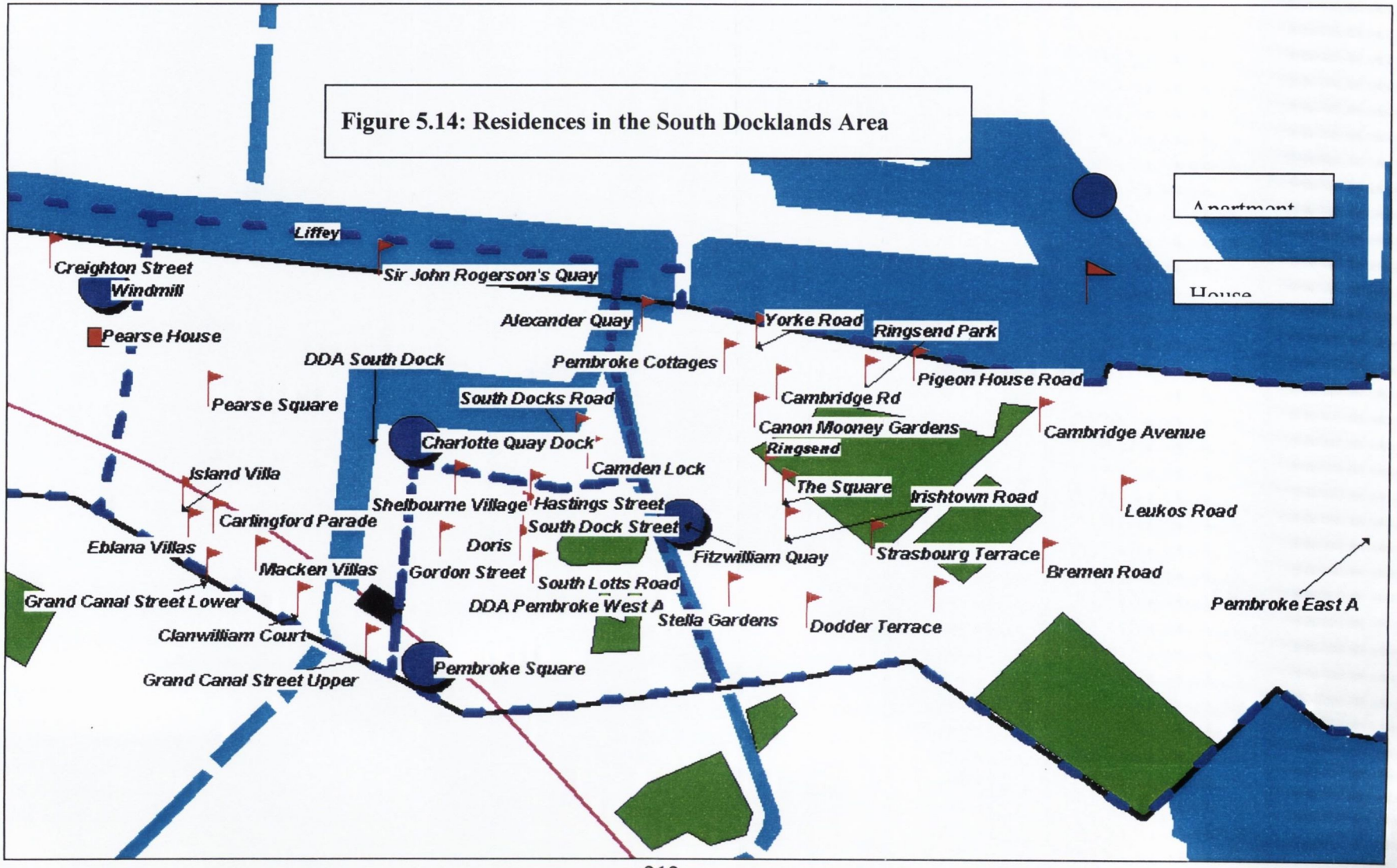
Figure 5.14: Residences in the South Docklands Area
Apartment
House
Liffey
Creighton Street
Windmill
Sir John Rogerson's Quay
Alexander Quay
Yorke Road
Ringsend Park
Pearse House
DDA South Dock
Pembroke Cottages
Pigeon House Road
Pearse Square
South Docks Road
Cambridge Rd
Canon Mooney Gardens
Cambridge Avenue
Charlotte Quay Dock
Ringsend
Camden Lock
Island Villa
The Square
Irishtown Road
Shelbourne Village
Hastings Street
Leukos Road
Carlingford Parade
South Dock Street
Doris
Fitzwilliam Quay
Strasbourg Terrace
Eblana Villas
Macken Villas
Gordon Street
Bremen Road
South Lotts Road
Grand Canal Street Lower
DDA Pembroke West A
Stella Gardens
Dodder Terrace
Pembroke East A
Clanwilliam Court
Pembroke Square
Grand Canal Street Upper

There are two distinct bus corridors in the area as shown earlier in Figure 5.2. Numbers 1, 2 and 3 run on the first corridor and for the purpose of this work are collectively referred to as Bus A. Numbers 5, 7, 7A, 8, 45, 46, 63, 84 run on the second corridor and are collectively referred to as Bus B. Catchment areas around these bus stops are mapped out at 500m contours along possible walking routes. These catchment areas were shown in Figure 5.4. It is these catchment areas that determine if any bus service is available to a trip coming from a particular residential location. The catchment maps are queried with the residential location maps. This query provides two boolean columns showing whether Bus 1 and Bus 2 is available for each residential location.

The catchment areas are also divided into zones relating to different stops. This information is also passed to the database through a query. Travel times can then be calculated for each journey. Catchment areas for the DART stations are mapped out at 500m, 1,000m and 1,500m contours. The 500m and 1,000m catchment was shown in Figure 5.5. It was decided to include the 1,500m catchment since in the survey it was found that some people did walk such a distance to a DART station. Each catchment area has a unique code that identifies the station used. This is necessary so that travel times can be calculated. The walking distance and station information is then queried with the residential location maps.

In summary two key tables are exported out of the GIS program into the conventional database. The first table contains information relating to each origin location and the second contains information relating to each destination location. The Origin table contains the following information:

- Name of residential area,
- Name of Ward that area is in,
- Apartment or house
- Bus A availability,
- Bus A zone,

- Bus B availability,
- Bus B zone,
- DART walking distance
- DART Station

The destinations are encoded with a numerical zone code. These zone codes are the same as those used by the DTO in their latest version of the Saturn model. The Destination table contains the following information:

- Ward name and code,
- Availability of Bus A for that destination,
- Average walking time for Bus A at destination end ,
- Availability of Bus B for that destination,
- Average walking time for Bus B at destination end,
- Availability of DART for that destination,
- Average walking time for DART at destination end,
- Availability of public transport with interchange for that destination,
- No public transport available for that destination,
- Frequency of Bus A,
- Frequency of Bus B.

Each piece of survey data has a particular origin and destination. The origin and destination fields are filled out in a manner consistent with that of the Origin and Destination tables. Relationships are created between the tables. In this case a link is

created between the residential area field in the Origin table and the Survey table. A second link is then created between the destination zone in the Destination table and the Survey table.

These three tables can then be combined through a query so that each piece of data contains all the necessary information relating to its trip. It is this query that is read into the model and all further calculations on the data are from within the model code.

5.7 Database and Neural Network Interface.

So that the neural network can be run in the form of a mode choice model the data is required to be in the form of a range of inputs that describes the important characteristics of the trip and the trip maker. The output of the neural network will determine the mode chosen. There will be a system of Boolean outputs relating to car, public transport, cycling and walking.

First of all the necessary interface for the trip characteristics will be explained. It was initially assumed that an output would be provided for each type of public transport. A fundamental part of this work is to be able to use the model as a tool for analysing the benefit of new public transport extensions. The network is shaped by the data that it is trained on and so such a network would not place any trips on a new mode that was not used in the training set. In order to take account of this it was decided that the choice between public transport modes would be considered as a lower order decision. As a result there are 4 inputs to the model that relate to characteristics of the public transport chosen.

The neural network requires the inputs to be in the form of an array. This information is stored in a database and read in to the network. The most work is required to convert the public transport data into the required form for the model. The first step is to find out what public transport is available. The data is checked to see if any of the public transport modes are available at both the origin and the destination. When a public transport mode is available at both, then travel time and service frequency can be calculated for that mode from the data. The travel time includes the walking time at

both ends of the journey and the waiting time for the public transport vehicle to arrive. Waiting time is taken to be on average half of the headway time between vehicles. So if a public transport service frequency is one vehicle every 10 minutes then the waiting time is taken to be 5 minutes.

If no direct public transport service is available then the data is checked to see if the trip can be made combining public transport modes or routes. Again a travel time and service frequency would be calculated for this.

The available public transport options are then taken and compared to see which is the best option. The choice is made on overall travel time. Where this results in a tie than the public transport mode with the higher frequency of service is chosen. When the decision is made, all of the relevant public transport data is stored into the public transport inputs. A separate variable stores which public transport mode was chosen. This variable remains outside of the neural network process and is only recalled if the neural network output predicts that public transport will be used. The correct public transport can then be associated with that particular trip.

There are in fact five proposed input variables relating to public transport:

- Travel time,
- Service frequency,
- Walking time at origin and destination ends,
- Public transport mode type,
- Interchange

There were some gaps in the travel time data, in the questionnaire responses, and so it was necessary to develop a procedure for completing these fields. As there are only a finite number of stops on public transport the travel time for bus and DART was filled in by looking to see the length of time it took other trip makers to make the same journey.

A service frequency of one bus every 4.5 minutes was found to be the best frequency public transport available in Dublin. All of the other frequencies are therefore scaled to this with a frequency of 4.5 minutes corresponding to '1'. Each frequency is calculated by finding the inverse and then multiplying by 4.5. The lowest frequency is where there is only one bus or train every hour and this corresponds to '0.07'.

The walking time input is formulated so that a trip that has the shortest walking time (10 minutes – 5 minutes at either end of public transport trip) has a value of '1'. The maximum walking time is taken to be 30 minutes and such a trip will have a walking time input of a value of '0'. The rest of the walking times are linearly distributed between the maximum and minimum values.

An input for public transport mode type (PTMT) was included in an attempt to have an input showing which public transport mode was being used in the comparison with other modes. Values were assigned to the different public transport modes to give them significance. DART was assigned a value of '1' and bus a value of '0.5'. Where the public transport option consisted of more than one public transport mode or route a value of '0.2' was assigned. These values have no quantitative value and should be thought of as labels, which the neural network can comprehend.

Interchange is given a value of unity if it is necessary to travel by more than one bus or more than one form of public transport. If the journey can be completed on just the one mode then Interchange is give a value of zero.

Where travel times for the other modes were not given in the responses the time was calculated by multiplying the distance by an average speed for each mode. The most accurate travel time data for a particular mode will be contained in the data of those who actually travel by that mode regularly. Therefore an average speed is calculated from the relevant data set for each mode. The speeds were calculated as follows:

- Car 14.2 km / hour
- Cycling 10.0 km / hour

- Walking 5.0 km / hour

It was felt that this was too much of a generalisation for car travel in Dublin and so a further step was taken. The observed car trips were split up according to three different destination areas and a separate average was calculated for each. The zones and their average speed are as follows:

- City centre zones 9.2 km/hr,
- Inner suburb zones 12.5 km/hr, and
- Outer suburb zones 22.3 km/hr.

Maren et al. (1990) suggests that where the range of values for a particular input is large than the logarithm of the variable should probably be used. This was found to be helpful in the pilot study in section 4.6 and so it is tested here again. The travel time is read in minutes and is presented in terms of a reversed log scale as follows:

$$Input\ travel\ time = 1 - Log_{180}(travel\ time)$$

The maximum travel time is assumed to be 3 hours – this caters for the possibility of people walking or cycling some of the longer distances – and so a base of 180 minutes is used. Using a Log scale will also result in the input values being between '0' and '1'. There is potential that such a scale will give greater significance to the small differences in travel times over the shorter journeys. It is suggested that travel time differences would be less significant as journey times increase and other factors such as comfort of mode would become more important.

The travel time inputs are reversed so that the shortest travel time will approach a value of '1' whilst the longest will have a value of '0'. This was done to aid the network in taking account of an input that should have a definite positive effect on a particular outcome. A standard linear reversed scale will also be tested with the form:

$$Input\ travel\ time = 1 - (travel\ time / 180)$$

The maximum travel distance is assumed to be 80 km and so each distance term is divided by 80 to bring it into the correct range. The value is then subtracted from '1' so as to reverse its representation. The shorter distance gets a values of close to '1' whilst the longer journeys get a value approaching '0'.

In summary the trip characteristics consists of the following:

- Distance,
- Car time,
- Public transport time,
- Bicycle time,
- Walk time,
- Walking Distance,
- PT Frequency – frequency of public transport service,
- PTMT (Public transport mode type),
- Interchange Necessary → if travelling by public transport is it necessary to change route.

The rest of the inputs relate to personal characteristics of the trip maker. As learned from the pilot study the personal characteristics are grouped into as small a number of inputs as possible. The sex of the person is input using one boolean variable, male corresponding to '1' and female '0'. Age is input using one variable with different values for different age categories as follows:

- under 25 → 1.0,
- 25 – 34 → 0.8,
- 35 – 44 → 0.6,

- 45 – 54 → 0.4,
- 55 – 65 → 0.2, and
- Over 65 → 0.0.

There are 2 inputs relating to the other occupants in the household. One relates to whether there are other adults in the house and the other two whether there are children in the house. The input relating to children does not differentiate according to their ages for two reasons: (i) difficulty in expanding data to full study area and (ii) keeping number of inputs down. The two inputs are boolean and so in the case of the adult's input it is assigned a value of '1' if there are adults present and '0' if not. One variable is used to show if the residence is a house, '0', or an apartment '1'.

The next boolean inputs relate to the use of the car and are as follows:

- Car availability – '1' if a car is available for the trip otherwise '0',
- Car parking available – '1' if parking is available at work otherwise '0'.

An input is not formulated for people being 'tied' to using a car as it was realised that future prediction of such a variable would not be possible. It is assumed that everybody has the option of paying for somewhere to park and so with reference to the question in the questionnaire (Appendix 4) the options 'free at work' and 'free in public place' are included in evaluating the car parking available input as '1'.

Starting time is not included as an input for this work. An assumption is made that the majority of people wish to arrive at work at approximately 09:00 and would do so if traffic congestion allowed. The model therefore takes account of all the morning trips to work and produces totals per mode. It is possible that these totals would relate to 1 hour if the infrastructure allowed.

An input for salary is also excluded. An estimate of salary for each trip maker in future new developments would be at best a guess and so would adversely effect the results.

Therefore in summary the personal characteristics are as follows with the identifiers that will be used from this point on:

- Sex,
- Age,
- Children,
- Adults,
- Apartment,
- Car Available,
- Parking Available.

Different combinations of the personal characteristics and trip characteristics can be combined to provide a set of inputs that can be presented to the neural network. How this is done and the methodology used to compare the different input sets will be described in the subsequent subsections.

The outputs of the neural network are in the form of four outputs, each of which relates to a mode:

1. Car,
2. Public transport,
3. Bicycle,
4. Walk.

The survey data being used to train the network has known outputs and so these are read into a separate array so that the network can compare its generated outputs with the actual outputs. In the case of the survey data the output relating to the mode chosen is given a value of '1', whilst the rest of the modes are given a value of '0'.

5.8 Running the Neural Network

When the neural network program is run the first thing that happens is that a dialog box opens from which a set of inputs can be selected. The actual inputs that have been selected are stored in memory. Calling the function 'Create' creates the network. The code creates a neural network object with the desired number of inputs. As the network is created the user is asked to fill in the following network parameters:

- Number of layers,
- Number of middle layer nodes,
- Learning rate,
- Momentum,
- Tolerance,
- Maximum error.

These can be adjusted and will affect the performance of the model as explained in the previous chapter. Once the neural network has been created then it is ready to be trained on the example set of data. 60% of the survey data is used to train the model whilst 40% is kept back to test the model's predictive powers. The 'Training' function is called and the model trains on the data over a number of iterations. The data is selected in a random order for each training iteration.

After each data item is presented to the network the four generated outputs are compared to the actual outputs and errors are propagated back through the network as described in the last chapter. A data item is considered to be trained correctly when each of the generated outputs has a value that is within the tolerance set to the actual output. At the end of each iteration the number of data items that have been trained correctly is recorded. Training is complete when all of the data items have been trained correctly. This may not always be achieved and other factors may be required to determine the stopping point.

When training has been completed then the test set of inputs can be presented to the network. The 'Run' function is called and the network generates outputs from the test set. Since the generated outputs are not in the form of one '1' and the rest '0's it is necessary to select the output with the largest value as being the mode chosen. As an output is generated for each data item it is compared to the actual output. If they match then the network is considered to have predicted that data item correctly. When outputs have been generated for all of the test set, the total number of outputs predicted correctly is an indication of the predictive powers of the network.

5.9 Testing Significance of Inputs

In this section the network is tested to see which inputs assist in training so that its predictive powers are the most accurate. The 'train' and 'run' functions are combined in one function called 'iterate'. This function enables the network to be tested on the test data during training and results recorded every 100 iterations. The results are in the form of generated outputs for each mode as a percentage of the number of actual outputs for each mode. 100% for any particular mode will mean that the model predicts the correct number of journeys for that mode.

Over the first few iterations the output is very varied and inaccurate but after a few thousand iterations it begins to settle down and approach convergence. The choice of inputs and the network configuration will determine how long it takes for the model to converge or whether it converges at all. From observation it was decided to consider that the network had converged when it produced the same results for 1,000 iterations.

A standard network configuration is used initially with the following characteristics:

- 3 layers,
- Number of middle nodes equals number of input nodes,
- Learning rate at 0.25,
- Momentum at 0.9.

As shown earlier 3 layers is usually sufficient for a backpropagation neural network to train. Also in the pilot study it was shown that in general the network will perform best when the number of middle nodes equals the number of input nodes. The proportion of middle nodes to input nodes will be tested further in chapter 6 when the inputs have been chosen.

As discussed earlier the learning rate is usually in the range 0.05 – 0.25. The higher figure is selected to enable the model to reach a close approximation to its optimum more quickly. The output will be oscillating around the optimum and so the actual results will depend on the particular point where the iterations are stopped. The learning rate will be reduced when testing the final versions and so accurate convergence should be achieved. The momentum term is left at the high value of 0.9 to stabilise the model. This term aids the network to continuously move towards convergence.

Table 5.15 shows the input configurations tested and the relative outcomes. Three outcomes are presented in the table:

- Training → percentage of data items trained correctly,
- Predict → percentage of test data items predicted correctly,
- Error → total error accumulated over whole training set.

The error is calculated by taking the sum of the four output node errors over the whole training set. The output node error is calculated using Equation 4.5.

Six of the inputs (four travel times, car availability and parking availability) are deemed to be essential for the network to get a basic picture of the trip being made and so are included in each of the test runs. The 4 travel time inputs are in log form for this series of test runs.

Test run A contains just the first 6 inputs (see Table 5.15) and only 70% of the data items are trained successfully and there is a total error term of 9.2. The following 4 test

runs (B – E) try each of the personal characteristics individually. Any one of these inputs has the effect of increasing the proportion trained correctly to approximately 80% and reducing the total error term to between 5 and 7. The proportion that are predicted correctly with the additional input varies. The inputs 'age', 'children' and 'adults' all predict about 65% of the data set correctly whilst the input 'sex' only predicts 56% correctly.

	A	*B*	*C*	*D*	*E*	*F*	*G*	*H*
Car time	✓	✓	✓	✓	✓	✓	✓	✓
P T time	✓	✓	✓	✓	✓	✓	✓	✓
Bike time	✓	✓	✓	✓	✓	✓	✓	✓
Walk time	✓	✓	✓	✓	✓	✓	✓	✓
Car available	✓	✓	✓	✓	✓	✓	✓	✓
Car parking	✓	✓	✓	✓	✓	✓	✓	✓
Sex		✓						✓
Age			✓				✓	
Children				✓		✓		
Adults					✓	✓	✓	✓
Outcome								
Training (%)	70	81	79	78	81	87	87	87
Predict (%)	61	56	66	65	66	69	67	68
Error	9.2	5.5	6.7	6.1	7.2	3.3	2.9	4.3

Table 5.15: Version Outcomes 1.

The 'adults' input in version E provides the best outcome with 81% trained correctly and 66% predicted correctly. Versions F – H all have the input 'adults' combined with one of the other personal characteristics. This improves the proportion of data trained correctly in each version to 87%. There is also an improvement in the proportion predicted correctly and a large reduction in error for all three versions. The best result

is version F, which is achieved by combining 'adults' with 'children', and enables the network to predict 69% of the test data correctly.

Table 5.16 presents the next series of test runs. Using version F as a basis versions I and J contain the inputs 'age' and 'sex' individually and then version K adds in both. Versions I and J both result in another improvement in the proportion trained correctly. 93% of the data is trained correctly in both I and J compared to the 87% in version F. The predicted proportion is reduced to 63% for both compared to 69% in version F. Version K achieves a trained proportion of 98% and a predicted proportion of 66% with an error of 1.2. This means that version K is more accurately trained but has slightly reduced predictive powers.

	I	*J*	*K*	*M*	*N*	*O*	*P*
Car time	✓	✓	✓	✓	✓	✓	✓
P T time	✓	✓	✓	✓	✓	✓	✓
Bike time	✓	✓	✓	✓	✓	✓	✓
Walk time	✓	✓	✓	✓	✓	✓	✓
Car available	✓	✓	✓	✓	✓	✓	✓
Car parking	✓	✓	✓	✓	✓	✓	✓
Sex		✓	✓	✓	✓	✓	✓
Age	✓		✓	✓	✓	✓	✓
Children	✓	✓	✓	✓	✓	✓	✓
Adults	✓	✓	✓	✓	✓	✓	✓
Apartment					✓		✓
Distance						✓	✓
Outcome							
Training (%)	93	93	96	86	97	98	97
Predict (%)	63	63	66	63	66	68	62
Error	1.3	2.4	1.1	4.8	0.6	1.0	0.4

Table 5.16: Version Outcomes 2.

Version M has the same inputs as K except the travel time inputs are in a standard linear scale as opposed to being in a log scale. Comparing the outcomes to those for K it is apparent that the log scale is beneficial in aiding the network to develop the necessary internal relationships. The training proportion reduces from 96% to 86% and the error increases from 1.1 to 4.8. A smaller reduction in predictive power is apparent with a decrease from 66% to 63%.

Versions N, O and P seek to improve the predictive powers by testing the impact of two more inputs – 'apartment' and 'distance'. In version N the 'apartment' input improves the training proportion to 97%, the predictive proportion to 66% and reduces the error to 0.6. Version O shows that the 'distance' input improves training and predictive proportions to 98% and 66% respectively whilst the error improves to 1.0. Overall version O provides slightly better outcomes than version N, but interestingly when the two inputs are combined in version P the predictive outcome reduces to 62% well below that for N and O.

Table 5.17 presents the next series of tests using version K as the starting point. Versions Q – T test the impact of the 4 additional public transport inputs individually. All 4 of these versions have training proportions between 95% and 98% but the predictive proportions vary to a greater extent. The two best versions are Q and S where 69% and 67% of the data items are predicted correctly. This means that the inputs 'walking distance' and 'PTMT' do provide additional useful information to the network. In version U these two are combined, which results in 98% trained correctly but only 64% predicted correctly.

Versions V and X add the other two public transport inputs individually. The combination of 'walking distance', 'PTMT' and 'interchange' in version X results in 71% of the test data being predicted correctly. This is the highest value achieved in any of the test versions.

	Q	*R*	*S*	*T*	*U*	*V*	*X*	*Y*	*Z*	*AA*
Car time	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
P T time	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Bike time	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Walk time	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Car available	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Car parking	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Sex	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Age	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Children	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Adults	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Apartment									✓	✓
Distance									✓	✓
Walking Dist	✓				✓	✓	✓	✓	✓	✓
P T Freq		✓				✓		✓		✓
PTMT			✓		✓	✓	✓	✓	✓	✓
Interchange				✓			✓	✓	✓	✓
Outcome										
Training (%)	98	97	95	97	98	98	97	98	97	98
Predict (%)	69	60	67	62	64	63	71	68	69	67
Error	0.68	0.45	0.99	0.97	0.68	0.69	0.62	0.63	0.63	0.64

Table 5.17: Version Outcomes 3.

Eight of the versions are selected for the next stage of testing. This stage of testing investigates the proportion of outputs for each mode. It is necessary that the network can accurately predict outcomes for each mode without introducing a bias towards or away from any particular mode. Two new training and test runs are completed for each version. Table 5.18 shows the predicted outcome for each mode in terms of a percentage of actual output for that mode. 100% means that the correct number of people for a particular mode is predicted.

		Train	*Predict*	*Car*	*DART*	*Bus*	*Cycle*	*Walk*	*Accuracy*
K	1	97%	68%	139%	57%	100%	71%	81%	1.30
	2	97%	66%	127%	71%	150%	71%	83%	1.52
N	1	97%	67%	148%	29%	67%	71%	81%	2.00
	2	97%	64%	134%	29%	83%	71%	91%	1.60
O	1	96%	71%	95%	57%	100%	86%	113%	0.75
	2	96%	69%	123%	57%	83%	57%	100%	1.26
Q	1	97%	66%	125%	43%	150%	79%	87%	1.66
	2	97%	67%	127%	43%	167%	79%	83%	1.89
X	1	97%	67%	127%	100%	83%	64%	89%	0.91
	2	97%	69%	132%	86%	100%	50%	89%	1.07
Y	1	98%	64%	130%	43%	83%	107%	83%	1.28
	2	99%	68%	130%	57%	117%	79%	85%	1.26
Z	1	98%	68%	141%	71%	83%	71%	79%	1.37
	2	96%	69%	141%	57%	67%	79%	81%	1.57
AA	1	98%	68%	123%	114%	100%	79%	85%	0.73
	2	98%	68%	123%	129%	100%	71%	85%	0.96

Table 5.18: Test Data mode outcomes.

In Table 5.18 the first test run for version K results in a prediction that 39% more people will travel by car than actually do in the test data. The network predicts the correct number of bus travellers since 100% is shown in that cell. A sum is taken for each version, of the absolute differences from 100% for each of the modes. The final column shows the value calculated for each version. This value gives an indication of how accurately each version predicts the mode choice of the test data. Such a measure

of output performance is a novel idea and is put forward as an important tool for assessing the performance of neural network models with multiple outputs.

It can be seen that version AA has the smallest values for the two test runs and has a maximum of 29 percentage points variation from 100%. Version O gives a good result of 0.75 for its first test run and predicts 71% of the data correctly. The second run shows that the result is quite variable depending on the exact solution achieved by the network. It is important that the possible network solutions for any given version are within a small range from each other.

The next step is to test a variety of network configurations of version AA. Table 5.19 shows the outcomes on the test data for different quantities of middle layer nodes. The accuracy column shows that the networks with the following number of middle layer nodes have the best accuracy measure:

- 19 middle layer nodes → 1.09,
- 16 middle layer nodes → 0.88,
- 13 middle layer nodes → 0.68,
- 9 middle layer nodes → 0.95.

These configurations are tested over 5 runs each to provide an average measure of accuracy. It is important that the selected version should be able to consistently reach the best solution possible within a certain margin of error.

Table 5.20 shows the outcome for each of the 5 test runs on the 4 network configurations. The full table can be found in Appendix 5. It is evident that the 16 node configuration produces the best average accuracy measure at 0.84 compared to 0.98 for the 19 node one. The standard deviations are similar for these two configurations at 0.13 and 0.11 respectively. The other two configurations, 13 and 9, are considerably less accurate and consistent than 19 or 16.

Middle	*Train*	*Predict*	*Car*	*DART*	*Bus*	*Cycle*	*Walk*	*Accuracy*
20	98%	71%	134%	86%	50%	71%	87%	1.40
19	98%	65%	130%	129%	100%	71%	79%	1.09
18	96%	67%	123%	71%	183%	79%	81%	1.75
17	98%	66%	136%	86%	67%	79%	81%	1.23
16	98%	68%	123%	114%	83%	79%	87%	0.88
15	99%	65%	118%	71%	167%	57%	92%	1.65
14	98%	65%	130%	86%	133%	86%	77%	1.14
13	97%	65%	123%	100%	100%	64%	91%	0.68
12	99%	64%	91%	129%	233%	86%	92%	1.93
11	98%	63%	143%	71%	133%	57%	75%	1.73
10	96%	67%	123%	71%	183%	79%	81%	1.75
9	98%	68%	125%	71%	117%	93%	83%	0.95

Table 5.19: Testing Middle Layer Configurations

Middle	*Average*	*SD*
19	0.98	0.11
16	0.84	0.13
13	1.21	0.33
9	1.22	0.37

Table 5.20: Average Outcome over 5 tests for selected configurations.

Version AA with a 3 layer network and 16 middle layer nodes performs the best on the test data. This version will therefore be used in the next section where it is tested on the full study area.

5.10 Summary and Discussion

The study area is presented in terms of its transport characteristics and demographics. It was concluded that up until the new DART station at Grand Canal Street opened the DART did not provide a significant service for the residents of the area. The new station has quite a densely populated catchment area. A large proportion of the study area is served by one or both of the two bus corridors in the area. The demographics of the area have been changing quite dramatically over the last 10 years. There has been a big influx of working age people moving into the newly developed apartments.

The administration of a questionnaire based survey is described. This survey was posted to 3,500 residents in the area and a return rate of 10% was achieved. The data collected in the survey is analysed and presented to give a picture of the travel characteristics in the area. The mode split for the area was calculated to be:

- Car → 38%,
- Public transport → 12%,
- Cycling → 9%,
- Walking → 40%, and
- Other → 1%

That almost 50% of the commuters within the study area either walk or cycle to work was considered to be very significant. It shows the potential sustainability benefits of locating residential and employment generators close to each other. The lack of attention to this thinking in Dublin's future plans was noted.

The significance of car availability and parking availability is shown by the statistic that 71% of respondents with both a car and parking available to them drive to work. Another interesting slant to car and parking availability was highlighted, by presenting data on the proportion of people travelling by other modes that had both a car and parking available. It was shown that over 30% of DART and cycle users had both a car

and parking available whilst only 14% and 11% of bus users and walkers had both available. This was deemed to support the theory that rail based public transport has a greater potential for attracting car users.

This data is then compiled, through the use of a GIS application and a standard database, into the necessary form so that it can be input into the neural network mode choice model. The neural network input consists of a range of inputs, which describes the important characteristics of an individual trip and its trip maker. The network output will be the mode chosen by that individual trip maker. Much testing and development was required to compile the input values into a form so that the neural network model would be able to distinguish between the range of values for each input.

The shape of the transfer function means that for an input variable like travel time, that might vary from about 5 minutes to over 60 minutes, it would pass a value of '1' for all of this range. To resolve this all of the input variables were scaled to values between '0' and '1'. Literature suggested that where the input variable had a large range of values than a logarithm scale should be used. The purpose of such a scale is to make small changes in small inputs just as significant as large changes in large inputs. The use of a logarithm scale was tested against a linear scale for travel times.

The input variables are also grouped into as small a number of inputs as possible. Where the number of inputs is large in comparison to the number of data items then it is unlikely that the network will experience a large range of values for each input. It is important that the model is trained on as wide a range of values for each input variable as possible. This will enable the network to establish the significance of changes in value of a particular variable.

A large series of test runs were required to identify the best combination of data inputs and network configuration. Using the conclusions drawn in chapter 4 it was decided to use a network with 3 layers and the number of middle layer nodes equal to the number of input layer nodes. At this stage of the network development its performance was measured in three ways:

- proportion of correctly trained data items,
- proportion of correctly predicted test data items,
- an error term.

The first test run contained only the basic trip characteristics and the outcome was 70% trained correctly, 61% predicted correctly and an error of 9.2. This was significantly improved within the first series of runs by adding in some personal characteristics relating to sex, age and composition of household. Outcomes rose to 87% trained correctly, almost 70% predicted correctly and error terms between 3 and 4. Further testing of the personal characteristics found that the results varied when different combinations of these inputs were used. It appears that some inputs cause internal interactions that actually reduce the accuracy of the outcomes. An example of this is found with the 'apartment' and 'distance' inputs. Individually they improve the predictive performance and error terms, but when they are combined the predictive term reduced to 62%.

The benefit of a log scale for the time inputs was tested against a standard linear scale. It was found that the log version resulted in a higher proportion of correctly trained data. The proportion trained correctly was 96% for the log version and 86% for the linear. Improvements are found in the other measures as well with 66% predicted correctly compared to 63% and an error term of 1.1 compared to 4.8.

The addition of the public transport inputs further improved outcome performance. Various combinations of these inputs all achieved training outcomes of 97% or 98%. The version that included 'walking distance', 'PTMT' and 'interchange' achieved a predictive percentage of 71% and an error term of 0.62. This shows that this additional public transport information is necessary to assist the network in distinguishing what mode is chosen. Interestingly, even though the addition of public transport information maintains the training outcomes to 97% or 98%, the predictive percentage will vary considerably depending on what combination of inputs are used. This shows the

importance of investigating the predictive outcomes further in selecting the best network version.

The individual predicted outcomes for each mode were compared with the actual outcomes. An accuracy measure was defined which enables the version that predicts each mode most accurately to be selected. This accuracy measure is very important in the analysis of neural network models with multiple outputs. The proportion of middle layer nodes to input nodes was tested again. The test confirmed what was found in chapter 4, that the best results are achieved with the number of middle nodes being set equal to the number of inputs. It was also found that this configuration had the lowest standard deviation of the accuracy measure over 5 runs.

The version labeled 'AA' clearly produced the most accurate results. The analysis showed that the network doesn't necessarily converge to the same point each time and that different runs will produce slightly different results. From observation of the results version AA varied the least as well as being the most accurate. This configuration of the version consistently produced a predictive percentage of 68%. To enable accurate prediction of mode choice over a study area this percentage would need to be higher. It is suggested that a higher predictive percentage could be achieved with a larger training data set. Such a training set could be provided by the 5 yearly population census.

The version 'AA' which was chosen contains the following 16 inputs:

Car time, Public transport time, bike time, walk time,

car available, car parking,

sex, age, children, adults,

apartment, distance,

walking distance, public transport frequency, PTMT, and interchange.

This version is used as the basis for testing the mode choice model on the full study area in chapter 6. Further tests will be required to check how the network performs when exposed to changes in public transport and land-use variables.

Chapter 6

Application of the Model to the Dublin Docklands

6.1 Introduction

In the first part of this chapter the expansion process necessary to provide base year data for the whole study area is explained. The future development potential of the area is outlined. Future transport developments are described and a possible light rail extension is postulated. The compilation of these future developments (both transport and land use) into the required data form is explained.

The model will then be tested on the base year and two particular future years. The variations tried in this series of testing will include:

- Varying the public transport routes available,
- Varying the car travel speed,
- Varying car-parking availability.

The final version and network configuration will then be identified which will be used to run future scenarios.

6.2 Base year data

The network is trained on survey data, which is only a sample of the total study area. Therefore to use the model for testing travel choices for the whole area it is necessary to expand out this survey data so that it corresponds to the whole study area. Use is made of Central Statistic Office (1996) demographic data for individual wards to provide aggregate figures. The desired end product of this process will provide data at individual level for every morning peak origin within the study area. It is therefore necessary to develop a data set with the individual characteristics of each person and their trip.

The personal characteristics that were considered significant in the previous subsection were as follows:

- Male / Female,

- Age Grouping,
- Household composition: other adults and/or children,
- Car availability.

The trip characteristics that were significant were as follows:

- Origin,
- Destination,
- Car Parking.

The rest of the trip characteristics are direct functions of the origin and destination location and so do not require any additional work in this section. The expansion is done in five distinct parts and figures will be presented in terms of Pembroke East A:

1. Development of matrix of numbers of people corresponding to each permutation of personal characteristics,
2. Compilation of number of origins from each residential area (street or apartment block),
3. Car availability data,
4. Allocation of the person matrix into the origin table,
5. Development of trip distribution.

Step 1:

The first part of the process requires the development of the personal characteristics matrix. This is developed from CSO household data (1996) with the following subsets:

- Male / Female,
- Other adults: Yes/No,

- Children: Yes/No,
- Age groupings.

Table 6.1 shows the 1996 origin personal characteristics matrix and Appendix 6 contains the details of how this table is compiled.

Adults	Y		Y		N		N	
Children	Y		N		Y		N	
Male or Female	M	F	M	F	M	F	M	F
< 25	146	102	62	43	1	10	4	2
25 - 34	216	154	92	65	2	14	19	20
35 - 44	149	107	63	46	2	10	19	19
45 - 54	109	76	47	32	1	7	17	8
55 - 64	94	71	40	30	1	7	20	23
> 65	0	0	0	0	0	0	0	0
Total	***714***	***510***	***304***	***216***	***7***	***48***	***79***	***72***

Table 6.1: 1996 Origin Personal Characteristics Matrix

Step 2:

Part 2 of this expansion process is to calculate the numbers of origins from each residential area. To do this it was first necessary to compile detailed information on the numbers of households in each street or apartment block. Thoms street directory (Thom's 2000) provides the numbers of households on each street for the whole of Dublin. Table 6.2 shows the information compiled for Pembroke East A.

The data in Table 6.2 can be compared to the demographic data in Table 6.1. The demographic data is from the last census, which was compiled for 1996. This means that to compare the number of dwelling units it is necessary to do so in 1996 figures. The data in Table 5.5 showed that the numbers in the 1996 census were as follows:

- Houses: 1,048 units,

- Apartments: 455 units.

Street Name	*No Units*	*H/A*	*Adults*	*Children*	*Male*	*Female*	*Male Origins*	*Female Origins*
Bath Street	36	H	72	35	33	39	24	19
Bremen Road	113	H	227	110	105	122	77	61
Bridge Street	8	H	16	8	7	9	6	5
Cambridge Avenue	30	H	60	29	28	32	21	15
Cambridge Rd H	6	H	12	6	6	6	5	3
Cambridge Rd A	38	A	38	0	18	20	0	0
Canon Mooney Gds	80	A	191	19	88	103	64	51
Church Avenue	9	H	18	9	8	10	6	4
Ennis Grove	27	H	54	26	25	29	18	14
Irishtown Road	37	H	74	36	34	40	25	20
Kerlogue	60	H	121	58	56	65	41	32
Leukos Road	101	H	203	98	94	109	68	53
Londonbridge Road	18	H	36	17	17	19	13	9
Pembroke Cottages	96	H	193	93	89	104	65	52
Pembroke Street	19	H	38	18	18	20	13	10
Pigeon House Road	35	H	70	34	32	38	23	19
Ringsend Park	92	H	185	89	86	99	64	49
Rope Walk Place	45	H	90	44	42	48	31	23
St Patrick's Villas	52	H	104	50	48	56	36	27
Stella Gardens	76	H	153	74	71	82	52	41
George Reynolds	188	A	448	45	207	241	153	117
Strand Street	5	H	10	5	5	5	4	3
Strasbourg Terrace	5	H	10	5	5	5	4	3
The Square	22	H	44	21	20	24	15	12
Thorncastle Street H	5	H	10	5	5	5	4	3
Thorncastle Street A	188	A	448	45	207	241	153	117
Yorke Road	128	H	257	124	119	138	87	68
Total Pre-1996	***1,519***		***3,182***	***1,103***	***1,473***	***1,709***	***1,072***	***830***
Alexander Quay	35	A	83	8	38	45	28	23
Dodder Terrace	12	A	29	3	13	16	9	8
Fitzwilliam Quay	111	A	264	26	122	142	107	70
Total Post-1996	***158***		***376***	***37***	***173***	***203***	***144***	***101***
TOTAL UP TO 2000	***1,677***		***3,558***	***1,140***	***1,646***	***1,912***	***1,216***	***931***

Table 6.2: Residential Area

Table 6.2 gives the following total numbers of houses and apartments in 1996 figures:

- Houses: 1,025 units,
- Apartments: 494 units.

The small reduction in housing numbers is probably due to change of use or demolition for new developments. Any other differences in data must be due to one or more of the following:

- Unoccupied dwellings at time of 1996 Census,
- Errors in 1996 Census, and/or
- Errors in street compilation in Thoms Directory (Thom's, 2000).

The number of trips for each residential area are shown in Table 6.2. The compilation of these figures is explained in Appendix 7. To be consistent with CSO data, which is based on 1996, the three developments since 1996 are removed and so the 1996 origins would be as follows:

- Male: 1,072 origins
- Female: 830 origins

This corresponds closely to the numbers of origins calculated directly from CSO data for the first part of this process. These were:

- Male: 1,104 origins
- Female: 846 origins

It is therefore assumed that the origin matrix determined in Table 6.1 relates directly to the residential origins in Table 6.2 with the three post-1996 developments removed. The next step required is to determine the personal characteristics matrix for the three post-1996 apartments. This matrix will be derived from Table 6.3, which is a personal

characteristics matrix for all the post-1996 apartments in the south Docklands area. Table 6.3 is derived from data compiled from the questionnaire based survey of the area. From the table it is apparent that the new apartment complexes consist largely of young adults, in their twenties or early thirties, with no children, sharing accommodation.

Adults	Y		Y		N		N	
Children	Y		N		Y		N	
Male or Female	M	F	M	F	M	F	M	F
< 25	3	2	26	29	1	0	1	0
25 - 34	4	4	78	81	2	2	12	11
35 - 44	1	2	8	7	0	2	5	4
45 - 54	1	1	3	2	0	0	4	1
55 - 64	0	0	0	0	0	0	1	0
> 65	0	0	0	0	0	0	0	0

Table 6.3: Dockland Apartments Personal Characteristics Matrix

Table 6.4 is the personal characteristics matrix for the three post-1996 developments in Pembroke East A, Fitzwilliam Quay, Dodder Terrace and Alexander Quay. It is calculated by reducing Table 6.3 down to the appropriate number of origins for males and females in the three appartments:

- Male: 144
- Female: 101

Table 6.4 can then be added to Table 6.1 to give a personal characteristics matrix for 2000. This data is shown in Table 6.5. The matrix in Table 6.5 has a total of 1,248 male origins and 947 female origins. This compares with Table 6.2 where there are 1216 male origins and 931 female origins. It is decided to reduce Table 6.5 to the origin levels of Table 6.2 which is based on the number of dwellings identified using

Thoms street directory (Thom's, 2000). Table 6.6 contains the final version of the personal characteristics matrix for 2000.

Adults	Y		Y		N		N	
Children	Y		N		Y		N	
Male or Female	M	F	M	F	M	F	M	F
< 25	3	1	25	20	1	0	1	0
25 - 34	4	3	74	55	2	1	11	8
35 - 44	1	1	8	5	0	1	5	3
45 - 54	1	1	3	1	0	0	4	1
55 - 64	0	0	0	0	0	0	1	0
> 65	0	0	0	0	0	0	0	0

Table 6.4: Post 1996 Apartment Personal Characteristics Matrix

Adults	Y		Y		N		N		Total		
Children	Y		N		Y		N				
Male or Female	M	F	M	F	M	F	M	F	M	F	
< 25	149	103	87	63	2	10	5	2	243	178	
25 - 34	220	157	166	120	4	15	30	28	420	320	
35 - 44	150	108	71	51	2	11	24	22	247	192	
45 - 54	110	77	50	33	1	7	21	9	182	126	
55 – 64	94	71	40	30	1	7	21	23	156	131	
> 65	0	0	0	0	0	0	0	0	0	0	
Total	***723***	***516***	***414***	***297***	***10***	***50***	***101***	***84***	***1,248***	***947***	***2,195***

Table 6.5: 2000 Personal Characteristics Matrix

For purposes of allocating the personal characteristic matrix to individual residences it is necessary to distinguish between apartments and houses. As shown earlier, the demographic shape of the post-1996 apartments is very different from the rest of the residences in the area. This leads to a decision to categorise only these new apartments

as apartments and treat the rest as houses. Table 6.4 is deemed to be the apartment personal matrix and the house personal matrix is derived by subtracting Table 6.4 from Table 6.6.

Adults	Y		Y		N		N		Total		
Children	Y		N		Y		N				
Male or Female	M	F	M	F	M	F	M	F	M	F	
< 25	145	101	85	62	2	10	5	2	237	175	
25 - 34	214	154	162	118	4	15	29	27	409	314	
35 - 44	146	106	69	50	2	11	23	22	240	189	
45 - 54	107	76	49	32	1	7	21	9	178	124	
55 – 64	92	70	39	29	1	7	20	23	152	129	
> 65	0	0	0	0	0	0	0	0	0	0	
Total	***704***	***507***	***404***	***291***	***10***	***50***	***98***	***83***	***1,216***	***931***	***2,147***

Table 6.6: Adjusted 2000 Personal Characteristics Matrix

Step 3:

The third step in this expansion process is the development of car availability data. From the survey data it is possible to develop a table showing the percentages of people with a car available for each of the sub-sections of the personal matrix. This data is shown in Table 6.7.

Where no data was observed for a particular sub-section (either car available or not) it was decided to seed it with a '1' in both tables giving a 50% car availability for that section. These seeded subsections are shown in bold and italics in the table. Where subsections had zero car availability then it was decided to place the minimum observed percentage rounded to the nearest 10%. It was felt this was necessary due to the size of the survey sample compared to the number of subsections. These cells are shaded grey in Table 6.7.

Adults	*Y*		*Y*		*N*		*N*	
Children	Y		N		Y		N	
Male or Female	M	F	M	F	M	F	M	F
< 25	50	50	33	18	100	***50***	20	***50***
25 - 34	75	44	60	57	100	20	63	62
35 - 44	73	67	78	78	***50***	100	50	69
45 - 54	100	33	83	56	50	20	100	100
55 - 64	100	***50***	75	20	20	50	75	50

Table 6.7: Car Availability Percentages

The percentages in Table 6.7 are used to apportion car availability over each ward's population but do not determine overall car availability. It was shown in section 5.5 that the overall car availability level differed greatly between each ward. As a result it is necessary to apply a factor to the car availability matrix so that the necessary overall car availability level is achieved. In the case of Pembroke East A 79% (Table 5.11) of the morning peak trip makers have a car available. Car availability is allocated separately over the personal characteristic matrices for houses and apartments. The house and apartment car available trip matrices are shown in Tables 6.8 and 6.9 respectively.

At this stage there are four matrices for each ward as follows:

- Car Available Apartment Matrix,
- Car Not Available Apartment Matrix,
- Car Available House Matrix,
- Car Not Available House Matrix.

Adults	Y		Y		N		N		Total		
Children	Y		N		Y		N				
Male or Female	M	F	M	F	M	F	M	F	M	F	
< 25	112	80	47	33	1	8	3	2	163	123	
25 - 34	166	120	71	51	2	11	14	16	253	198	
35 - 44	115	84	48	36	2	8	14	15	179	143	
45 - 54	84	59	36	25	1	6	13	6	134	96	
55 – 64	72	55	31	23	1	6	15	18	119	102	
Total									***848***	***662***	***1,510***

Table 6.8: House: Car Available Trip Matrix

Adults	Y		Y		N		N		Total		
Children	Y		N		Y		N				
Male or Female	M	F	M	F	M	F	M	F	M	F	
< 25	2	1	20	16	1	0	1	0	24	17	
25 - 34	3	2	58	43	2	1	9	6	72	52	
35 - 44	1	1	6	4	0	1	4	2	11	8	
45 - 54	1	1	2	1	0	0	3	1	6	3	
55 – 64	0	0	0	0	0	0	1	0	1	0	
Total									***114***	***80***	***194***

Table 6.9: Apartment: Car Available Trip Matrix

Step 4:

The fourth step is to allocate the individual parts of these matrices to particular residential areas. This process is based on the random allocation of each matrix to a particular apartment or housing group. A short computer program has been developed to process this.

The four personal characteristics matrices are read from a database table into a 2-d array (4 x 40). The data is selected randomly from the array by generating random location indices. If the value at the randomly selected array location is equal to zero another location is randomly selected until one is found that is greater than zero. The selected data is then allocated to either a house or apartment depending on which the array index refers to. The particular house or apartment is also selected randomly. The value of the personal characteristics array at this index is reduced by a value of '1', similarly the number of residences remaining at the location chosen is reduced by '1'. A new record is created in an output database table. The personal and residential location data is passed to it and the record updated. Within the same program a destination is selected for the trip according to the distribution determined.

Step 5:

The fifth and final step is to determine how to distribute these trips to particular destinations. A trip distribution matrix was developed from the original survey data and was based at a 32 strategic zone destination level. Figure 6.1 shows the coding system used for the strategic zones. The trip length distribution for the survey data is shown in red in Figure 6.2.

The distribution model used is a gravity distribution model (Ortúzar and Willumsen, 1994). This model estimates trips for each cell in a matrix without directly using the observed trip pattern. The formulation is a function of the total trip ends and the distance travelled and can be expressed as:

$$T_{ij} = A_i O_i B_j D_j f(c_{ij})$$

where A_i and B_j are balancing factors, O_i is total trip origins for zone i, D_j is total trip destinations for zone j and $f(c_{ij})$ is a generalised function of distance or travel costs between zones i and j. The function $f(c_{ij})$, often called the 'deterrence function' can be represented by an exponential function as follows:

$f(c_{ij}) = \exp(-\beta c_{ij})$ (Ortúzar and Willumsen, 1994).

The parameter β can be calibrated so that the estimated travel pattern replicates the observed pattern.

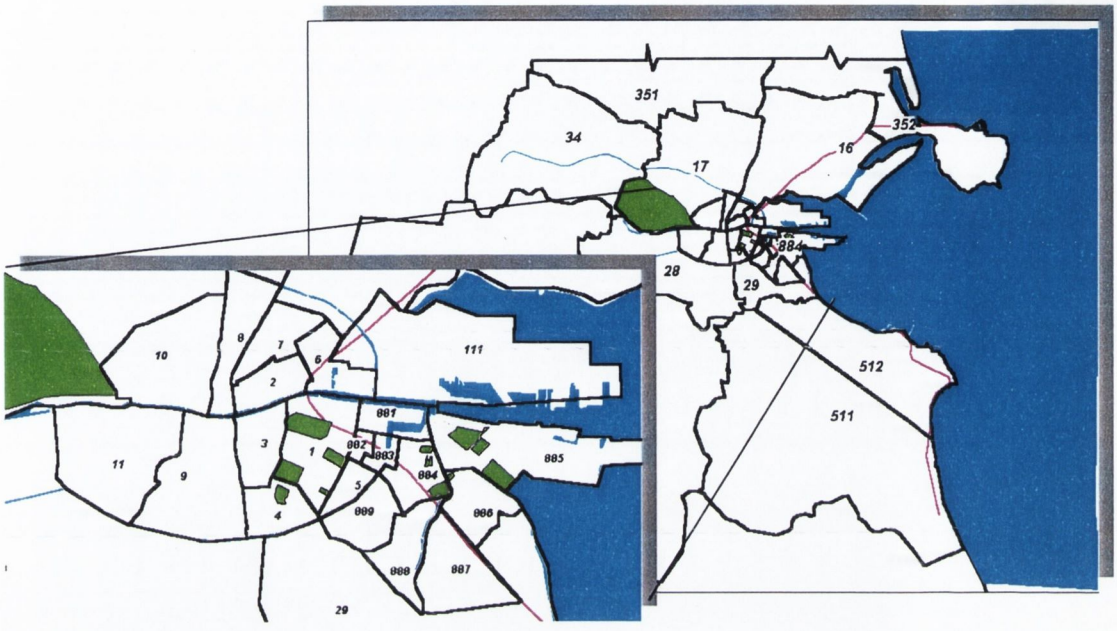

Figure 6.1: Strategic Zones

In this particular application the number of origins from the study area is predetermined and so the version of the gravity model required is said to be origin constrained. This means that B_j can be set to '1.0' and an equation for A_i derived:

$$A_i = \frac{1}{\sum_j D_j f(c_{ij})}$$

It is evident that this origin constrained form of the model is directly determinable without iterating and so it was possible to run a number of tests to calibrate β. The data required to run the distribution model includes the following:

- Total number of origins for each of the three study area wards – compiled earlier in this chapter,
- Total number of destinations to each of the strategic zones (DTO, 1996),

- Distances between origin wards and destination strategic zones – compiled from map.

This data was input into a spreadsheet and distributions were calculated for different values of β. Each of these distributions was run through the computer program and a trip length distribution was compiled from the data. The version with a β value of 0.16 was determined to produce the distribution closest to that observed for the area. This trip length distribution is shown in Figure 6.2 along with the surveyed distribution and the shape of the deterrence function.

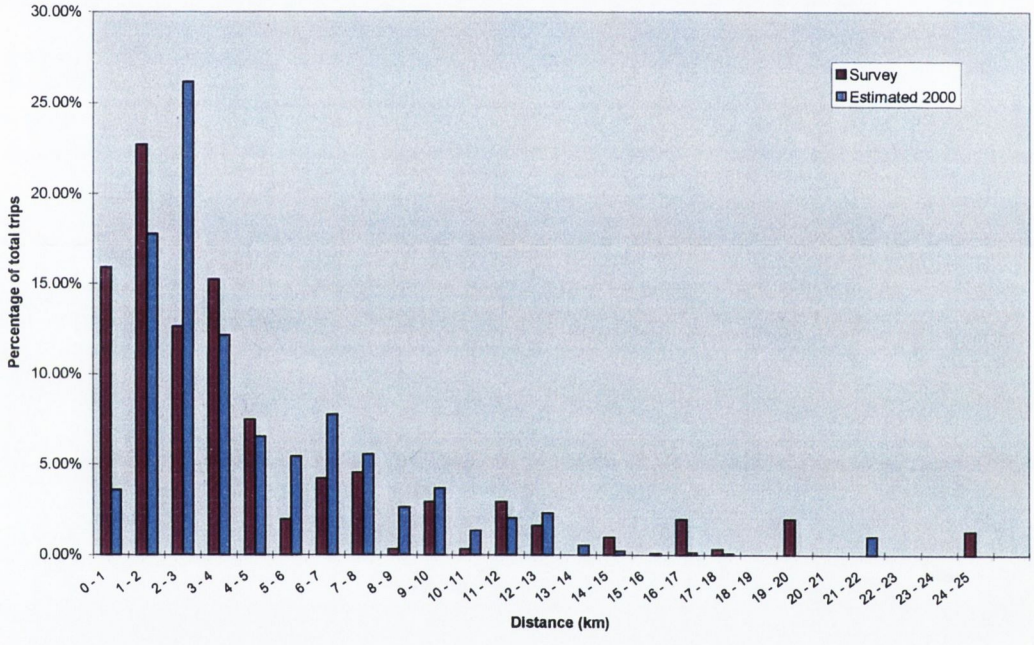

Figure 6.2: Trip Length Distribution

From observation it is clear that the distribution model significantly underestimates the proportion of trips of less than 1 km in length and also in the 1 – 2 km category. It was decided to adjust this by factoring up the trip destination totals for the study area zones – the zones that would be within 2 km of all the origins. Through a test process it was discovered that if the 5 study area zones were multiplied by a factor of '9' than the proportion of under 2 km trips became the same as that observed. Figure 6.3 shows the new trip length distribution.

The two categories covering 2 – 4 km are still not consistent with the observed distribution. It was decided not to try adjusting the distribution further as it would be necessary to adjust a large number of zones and if the category is considered as a 2 – 4 km category then the distribution is consistent with that observed. This trip distribution is then applied randomly to the origin trip matrix.

A table was constructed for distances between residential zones and destination zones. The OD distance is read from this table according to the particular residential zone and destination zone. There is potential that this part of the model could be automated with shortest route finding algorithms, if integrated with a fully functional GIS.

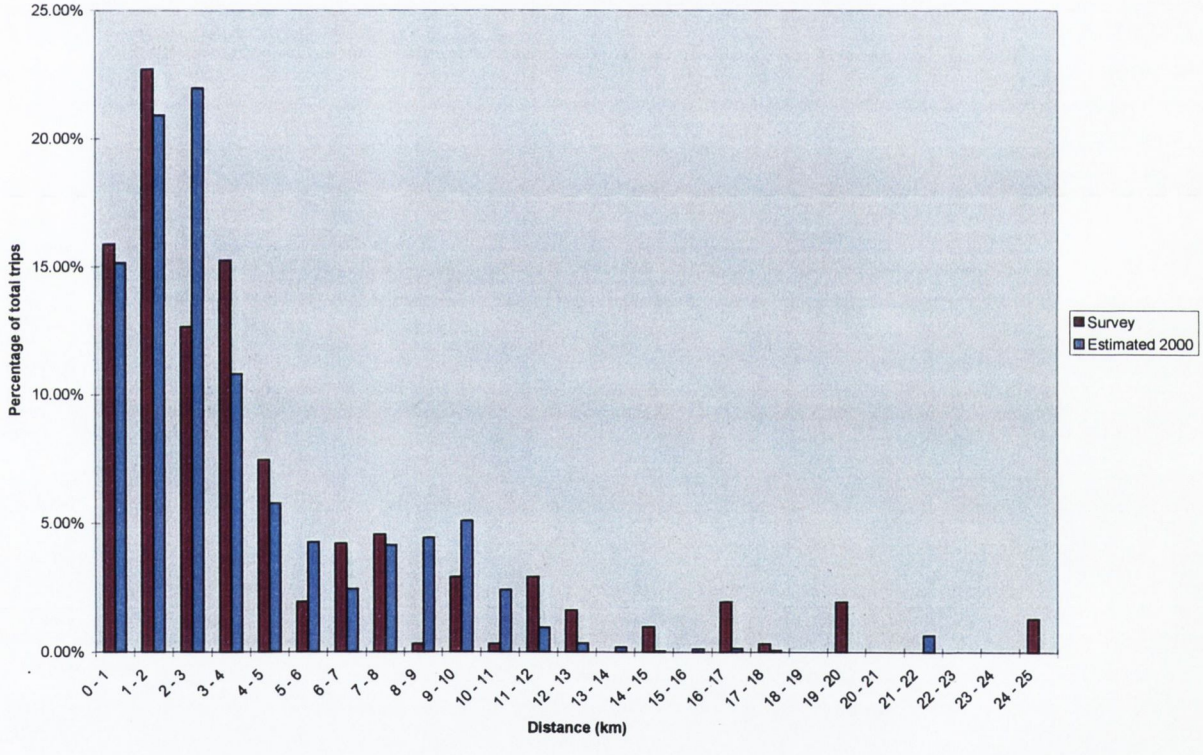

Figure 6.3: Adjusted Trip Length Distribution

Once the destination zone has been determined then parking availability can be addressed. It is assumed that trip makers with destinations outside of the city centre and its surrounding zones (canal ring) have free parking available to them. Parking availability is therefore set to true for each of these trips. For trips within the canal ring a certain proportion will not have parking available to them. From the survey there

were 168 trips with a central destination and 58 of these had parking available to them. This means that approximately 35% of trips with central destinations have parking available. Parking is randomly allocated to the trip makers, who have a central destination and a car available, so that the overall proportion is 35%.

This whole expansion process results in a complete set of data for each individual within the study area. The data set includes:

- Residence,
- Other adults,
- Children,
- Male/female,
- Age grouping,
- Car availability,
- Parking availability
- Destination,
- OD distance.

6.3 Development of South Docklands

The Docklands Master Plan (DDDA, 1997) divides up the Docklands area into six distinct sectors (Figure). The six sections are:

i. East Wall/North Strand

ii. Sheriff Street/North Wall Quay

iii. City Quay/Westland Row

iv. Grand Canal Dock

v. Ringsend/Irishtown

vi. Poolbeg Peninsula

As can been seen with reference to Figure 6.4 the three sections relevant to this work are Grand Canal Dock, Ringsend/Irishtown and Poolbeg Peninsula.

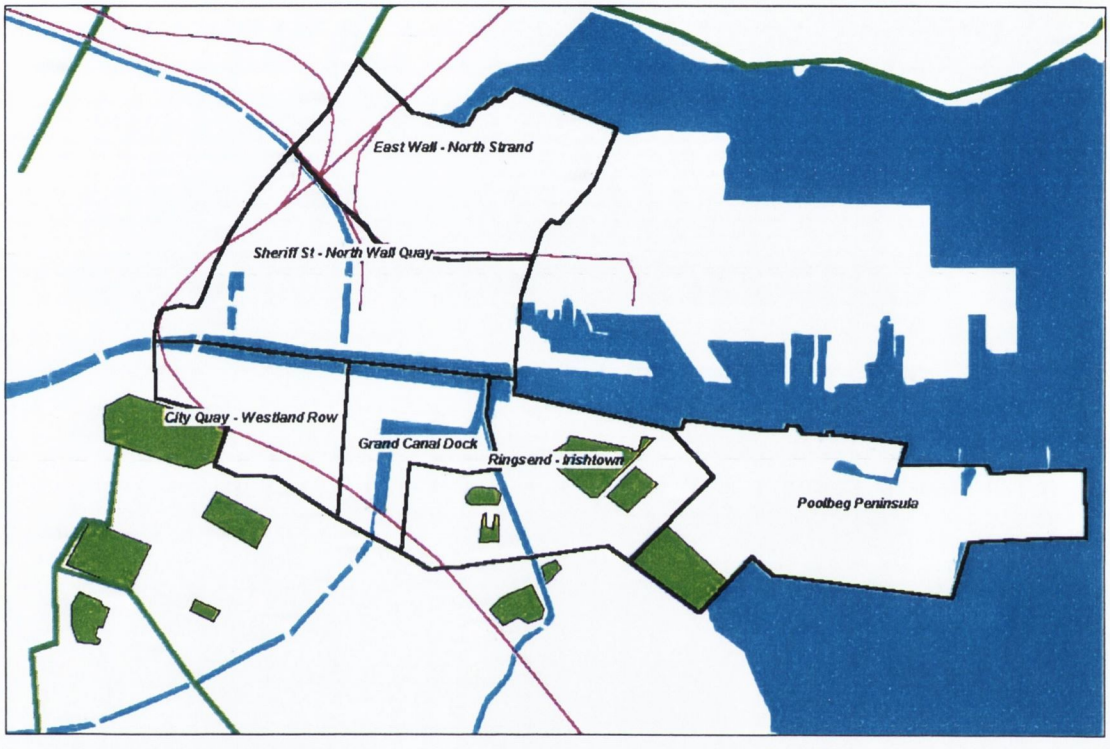

Figure 6.4: Dockland Sectors

The DDDA set out development objectives for each of these areas. In the case of the Grand Canal Docks an action plan was developed for the area. Each of these three sectors will be investigated in this section in terms of:

- Stated planning objectives,
- Completed developments,
- Planned developments,
- Potential future development.

This will enable estimates to be made on the future trip production in the area and so formulate data for future scenarios to be tested on the mode choice model.

6.3.1 Grand Canal Docks

The Grand Canal Docks area has great potential for development as it is on the edge of the Dublin 2/4 business districts and has large sites available for development. A map of this area is shown in Figure 6.5 with the key developments marked on it. In fact a number of developments have already taken place in the area as follows:

- Charlotte Quay Dock → 242 apartments,
- Camden Lock → 77 apartments,
- Grand Canal Plaza → 13,685 sq.m.,
- Esat Telecom → 6,500 sq.m.,
- Malt House → 2,200 sq.m.,
- Clanwilliam Square.

A problem, which is currently being remedied, is that the largest vacant site was a gas production site and so requires to be decontaminated before development can take place. This decontamination should be finished during 2001 (IT, 13/12/00). The greatest asset of the sector is the large water bodies which provide attractive views and make the development sites more desirable. It is a stated objective that public access should be maintained to all of the water edges (DDDA, 1999).

The DDDA (1999) propose that there should be a general mix of development of 40% commercial and 60% residential throughout the area. A desired objective in the action plan (DDDA, 1999) is to maximise the use of public transport, cycling and walking and keep car traffic to a minimum. The area has benefited with the opening of the new Grand Canal DART Station. This has improved public transport links to the area and there is a possibility of a north-south bus route through the area using the proposed

Macken Street Bridge to reach Connolly Station. In addition the following traffic management measures are desired:

- Environmental traffic cells to restrict vehicular access to the area,
- Parking guidelines which would stipulate lower levels of parking provision for new developments, than Dublin Corporation currently requires, so as to encourage the use of public transport.

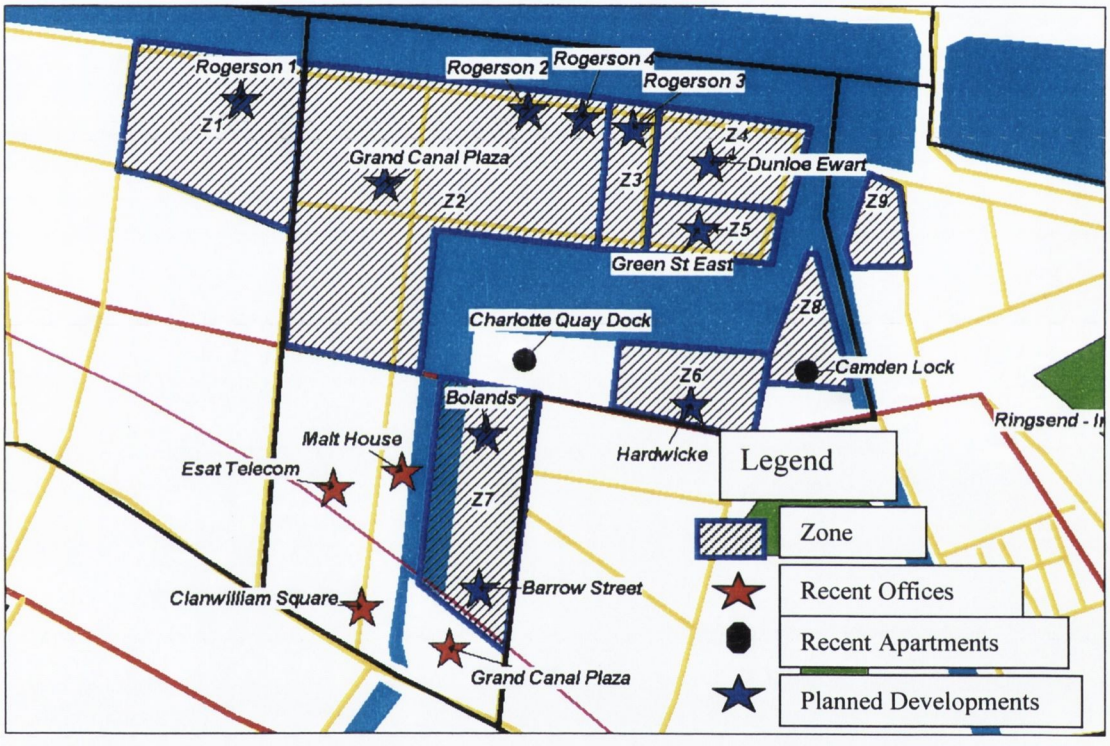

Figure 6.5: Grand Canal Docks Area

Table 6.10 shows the area of land covered by each of the zones shown in Figure 6.5. Gross area refers to the total area and net area is the area that is developed or is developable. The areas are calculated from the GIS map and a combination of two methods is used to gauge the size of particular sites:

- aerial photos,
- information from Irish Times on site purchases and developments.

The column with the heading 'Permanent' refers to sites that are unlikely to change use in the near future. 'Plans' refers to areas of land which are at various stages of being redeveloped and 'Industy/Warehousing' is land that will probably change use in the near future but at the moment there are no public plans.

The largest zone in Table 6.10 is Z2 within which the key site is the former gas production site where a new street pattern will be developed to enhance views and aid pedestrian flow through the area. This site, owned by the DDDA, is almost 9 hectares in size. The DDDA will organise the development of the site through joint ventures with private sector developers or through sales to developers that will comply with the action plan. With the split at 60/40 between residential and commercial the following quantities can be expected:

- Up to 1,300 apartments,
- 45,000 sq.m. of commercial space.

	Gross Area (hectares)	*Net Area (hectares)*	*Permanent (hectares)*	*Plans (hectares)*	*Industry /Warehousing (hectares)*
Zone 1	4.7	4.5	1.4	1.1	2.0
Zone 2	12.2	12.0	0.0	10.0	2.0
Zone 3	1.4	1.1	0.4	0.3	0.4
Zone 4	2.3	2.2	0.5	1.7	0.0
Zone 5	1.4	1.2	0.6	0.6	0.0
Zone 6	2.1	1.9	0.0	0.0	1.9
Zone 7	4.3	2.9	0.0	1.6	1.3
Zone 8	1.2	1.0	0.0	0.0	1.0
Zone 9	0.8	0.6	0.0	0.6	0.0
Total	*30.4*	*27.4*	*2.9*	*15.9*	*8.6*

Table 6.10: Development Potential

The DDDA already have plans for two office developments in progress. Agreement has been made with computer company Novell to develop their corporate offices in the

zone. A second development has just been put out to tender. The developments are shown in Figure 6.5 and their sizes are as follows:

- Grand Canal Plaza (Novell) → 13,500 sq.m.,
- Cardiff Lane/Sir John Rogerson's Quay → ~ 20,000 sq.m.

The remaining planned hectare Z2, which is not in DDDA ownership, is being developed in two separate developments on Sir John Rogerson's Quay labeled Rogerson 2 & 4 in Figure 6.5. The two developments will comprise of 8,000 sq.m. of office space and 10 apartments.

The rest of the planned developments within the sector are as follows:

- Rogerson 1 (Z1) → 23,000 sq.m. & 100 apartments,
- Rogerson 3 (Z3) → 6,000 sq.m. & 50 apartments,
- Dunloe Ewart (Z4) → 28,000 sq.m. & 231 apartments,
- Green Street East (Z5) → 103 apartments,
- Hardwicke (Z6) → 9,000 sq.m. & 125 apartments,
- Bolands Flour Mills (Z7) → 16,700 sq.m. & 70 apartments,
- Barrow Street (Z7) → 650 sq.m. & 143 apartments,
- East Link Bridge (Z9) → 27 apartments.

Referring back to Table 6.10 there is still a total of 8.6 hectares categorised as industry/warehousing. It is likely that once all of the above development takes place that site owners will capitalise on the increasing value of land and these sites will also be redeveloped.

6.3.2 Ringsend – Irishtown

This sector is predominately residential in terms of land-use and contains a number of large public open spaces. The sector is also home to a greyhound stadium and sports

pitches. The only large available site for development is another former gas production site. This site is over 3 hectares in size and is being redeveloped by Zoe Developments. Its location is shown in Figure 6.6 labeled as Zoe.

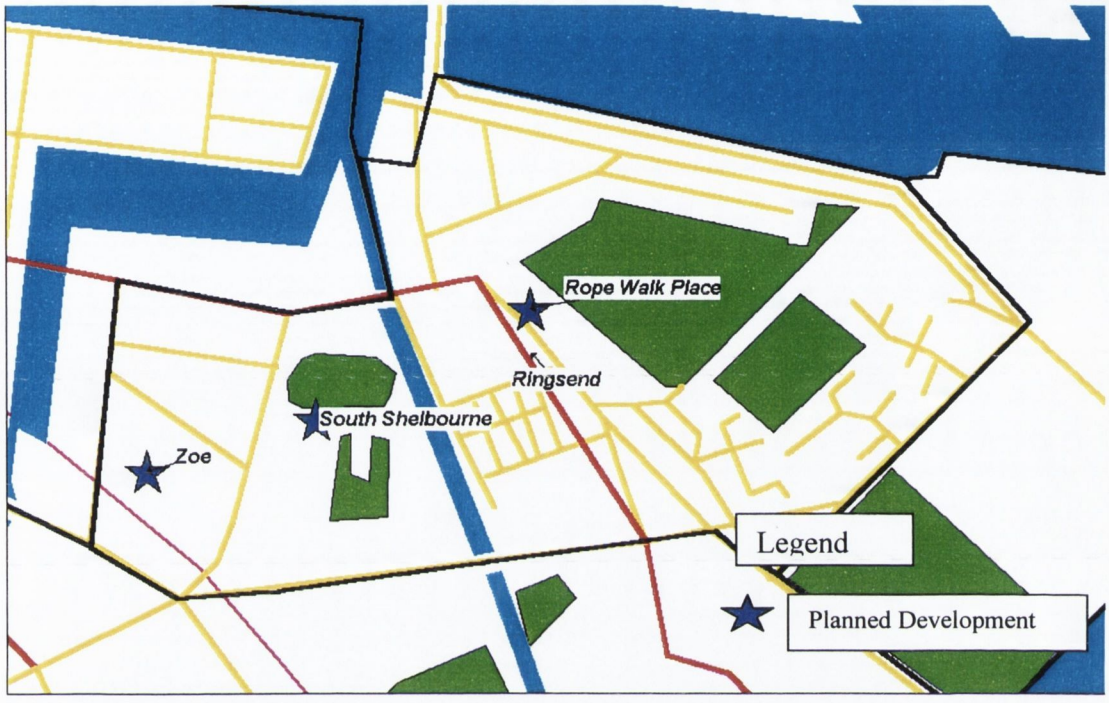

Figure 6.6: Ringsend-Irishtown.

The development quantities Zoe site are as follows:

- 630 apartments,
- ~ 7,000 sq.m. of media uses,
- 830 sq.m. of retail space,
- 10,600 sq.m. hotel.

This development was granted planning permission by An Bord Pleanála in January 2001 (IT, 11/1/01c). Permission was also granted to Bord na gCon (Irish greyhound board) for 101 apartments on a small site on part of Shelbourne Park race course.

Other developments in this sector will consist primarily of infill residential developments and some converting of small industries and warehouses to private residential use. Approximately 50 infill apartments/townhouses are being planned or constructed in the Rope Walk Place area.

The DDDA (1997) wishes to improve the Ringsend village area into an attractive civic space. Currently the volume of traffic passing through the area is very high and it is hoped that the traffic situation would be improved through the implementation of environmental traffic calming measures.

6.3.3 Poolbeg Peninsula

This sector has three distinct land-use functions:

- Major metropolitan utilities – electricity generation and waste treatment,
- Port related activities such as bulk handling and roll-on roll-off and haulage facilities,
- Natural habitat area on the southern boundary.

The DDDA (1997) recognises that the existing utilities and port related activities must continue in their present locations due to the scale of investment. There is potential to develop part of the peninsula between the two parks on the southern boundary. The peninsula is shown in Figure 6.7.

The DDDA (1997) proposed a Technopole concept for this area but little progress appears to have been made in planning it. A 5 hectare site labeled 'South Bank' in Figure 6.7 was sold in 1998 by Allied Irish Banks and reportedly bought by a housebuilding firm (IT, 11/11/98). This could have resulted in an application for a large scale residential development but instead a planning application has been put in for the following:

- 128,000 sq.m. of office space in 16 office blocks including a 30-storey circular glass tower,

- ~ 5,000 sq.m. of conference facilities,
- ~ 2,000 sq.m. of retail,
- a hotel,
- 2,000 car-parking spaces.

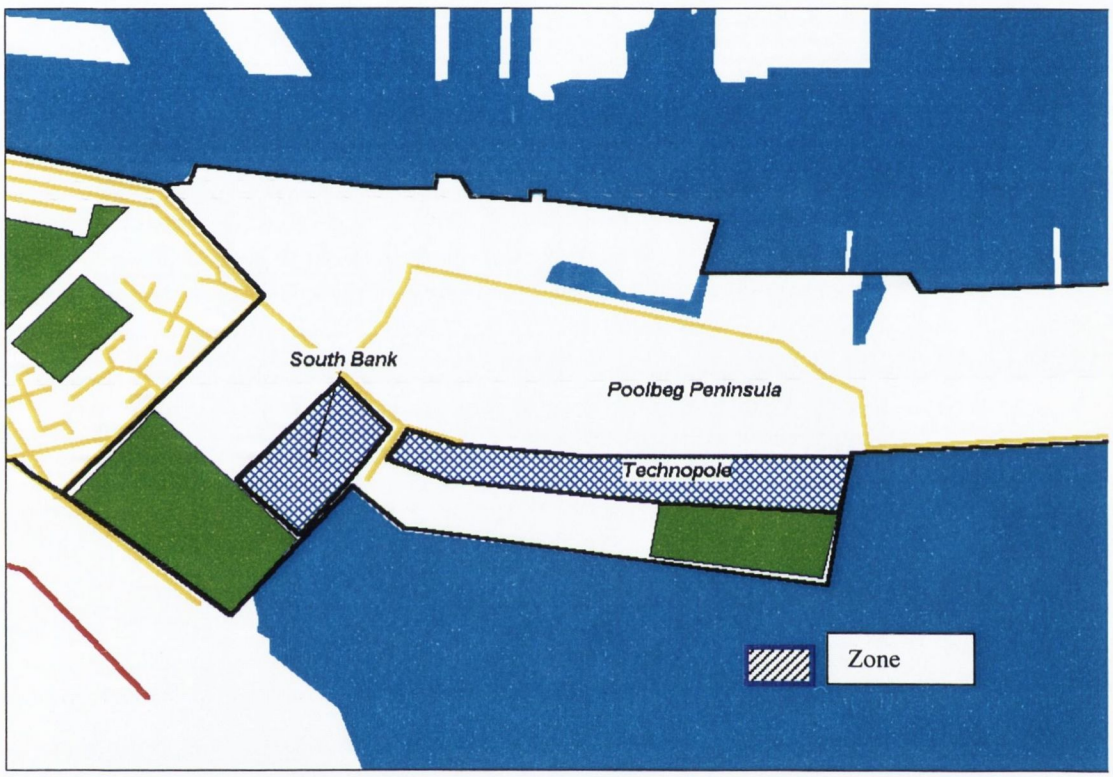

Figure 6.7: Poolbeg Peninsula

For such a development to take place access will have to be improved in the area. The roads would have to be upgraded and it would be imperative that quality public transport was provided. This development could easily become car dependent, like the office parks are along the M50 corridor, without the early provision of public transport. In fact public transport should be planned so that it is in place early on in the development process like in the IJburg development in the Netherlands (see Chapter 2).

6.3.4 Discussion

It is evident that the most change is going to occur in the Grand Canal Docks area. Large quantities of residential and commercial development will take place in this area over the next 10 years. In Ringsend the area will probably achieve some increased density in housing and will probably benefit from traffic calming and investment in the streetscape of the village. The key change in the Poolbeg Peninsula will be the development of the South Bank Site.

Due to the policy of mixed land-use in the Grand Canal Docks area there is the potential for people to live and work within the area. A DDDA objective is that the whole south docklands area would be served by public transport. Transport planning is not a function of the DDDA and so any new public transport developments are required to be developed between CIE, DTO and the Department of Transport and Public Enterprise.

6.4 Public Transport Proposals

The DDDA outlined two possible alignments for LRT in their Master Plan (1997). One of the routes was in the north Docklands and the other in the south Docklands. The alignments are shown in Figure 6.8 and are briefly described as follows:

- North Docklands route links Connolly Station, IFSC and Point Depot using Mayor Street alignment,
- South Docklands alignment runs over O'Connell Bridge to connect to developments around Grand Canal Dock and continues out through Ringsend and Irishtown,

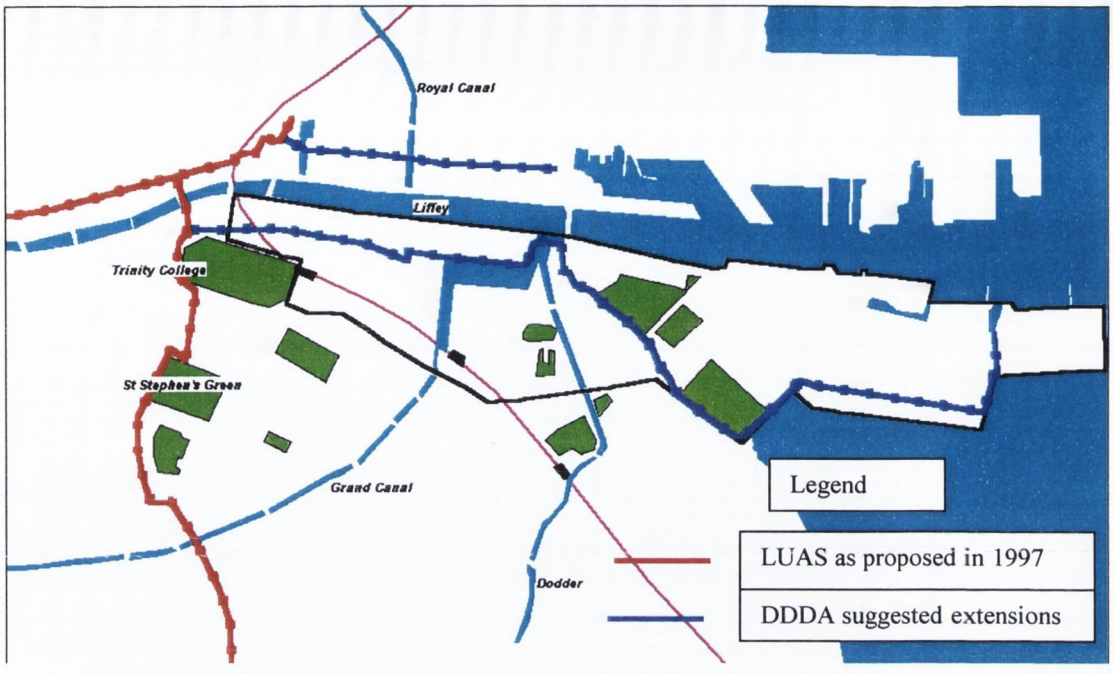

Figure 6.8: DDDA LRT Proposals

It is assumed that the North Docklands route will be implemented in a manner close to the proposed alignment. The South Docklands alignment is investigated to see if part of its alignment might be used to achieve the objectives set out in section 2 of this thesis. Some problems that are foreseen with the proposed southern route are:

- direct link to south city centre would not be an option with current proposal to link north south line by tunnel,
- bridge over Dodder/Grand Canal mouth would have to be either a high level bridge or a lifting bridge so that boats could navigate that section.

In order to link the north and south Docklands areas the Liffey must be bridged. It is therefore necessary to address this issue as a first step in establishing feasible routes, as the subsequent part of any route will depend on the bridging point. Dublin Corporation and DDDA both stipulate that any new bridge east of Talbot Memorial Bridge must be of the lifting variety so that ships can pass through. There are a number of possible points where a light rail line might bridge the Liffey and these are shown in Figure 6.9 and listed as follows:

1. Dublin Corporation's proposed Macken Street Bridge,

2. Dedicated light rail bridge joining New Wapping Street and Sir John Rogerson's Quay, or

3. East Link Toll Bridge.

The Macken Street Bridge option is attractive since it utilises infrastructure that is already planned for. In all information about the Macken Street Bridge there is mention that there will be space for dedicated public transport lanes and that LRT would be feasible. This alignment would also enable the route to pass through the new Grand Canal Dock developments (see Figure 6.9).

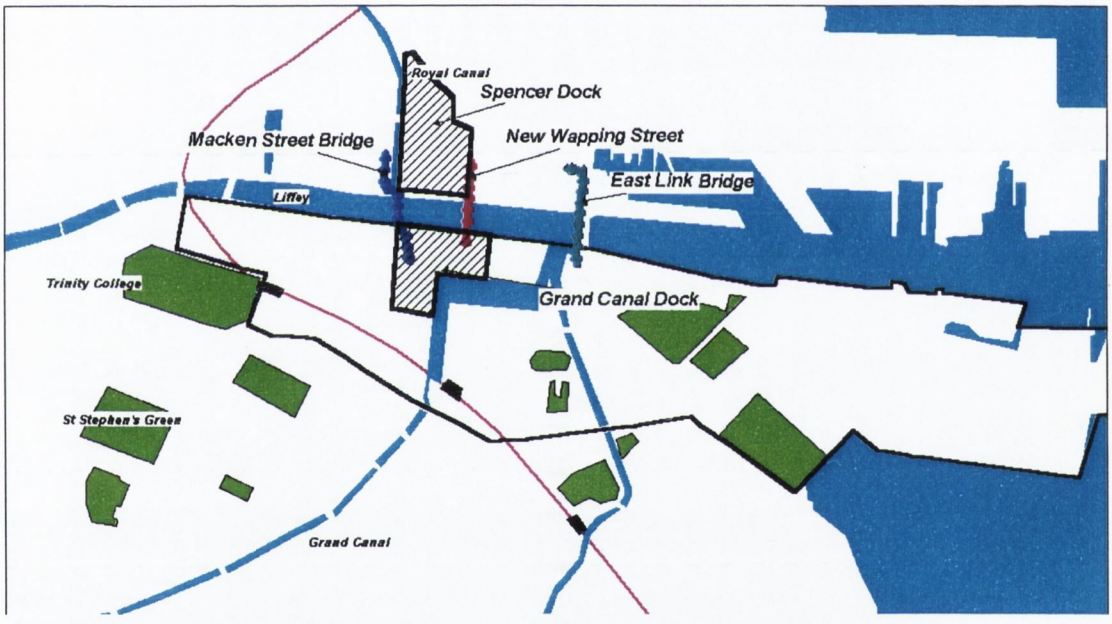

Figure 6.9: Liffey Bridge Options.

New infrastructure would have to be built for option 2, which would incur additional costs. The result would be to provide a crossing with totally segregated running. The other issues that result from option 2 are:

- the route would pass through the proposed Spencer Dock Development (see Figure 6.9),

- the route could be incorporated into the plans for the redevelopment of the former Gas Board Site (see Figure 6.9) that will soon be decontaminated.

To cross the Liffey at the East Link Bridge it would be necessary to construct a new bridge alongside the Toll Bridge. The principal benefit of this route would be that the route would have bypassed the Grand Canal and Dodder River and so avoided the necessity to bridge them. A significant problem with the alignment would be that it would miss the extensive developments around the Grand Canal Docks. Two distinct options have been identified for routes linking the north and south Docklands areas and are shown in Figure 6.10.

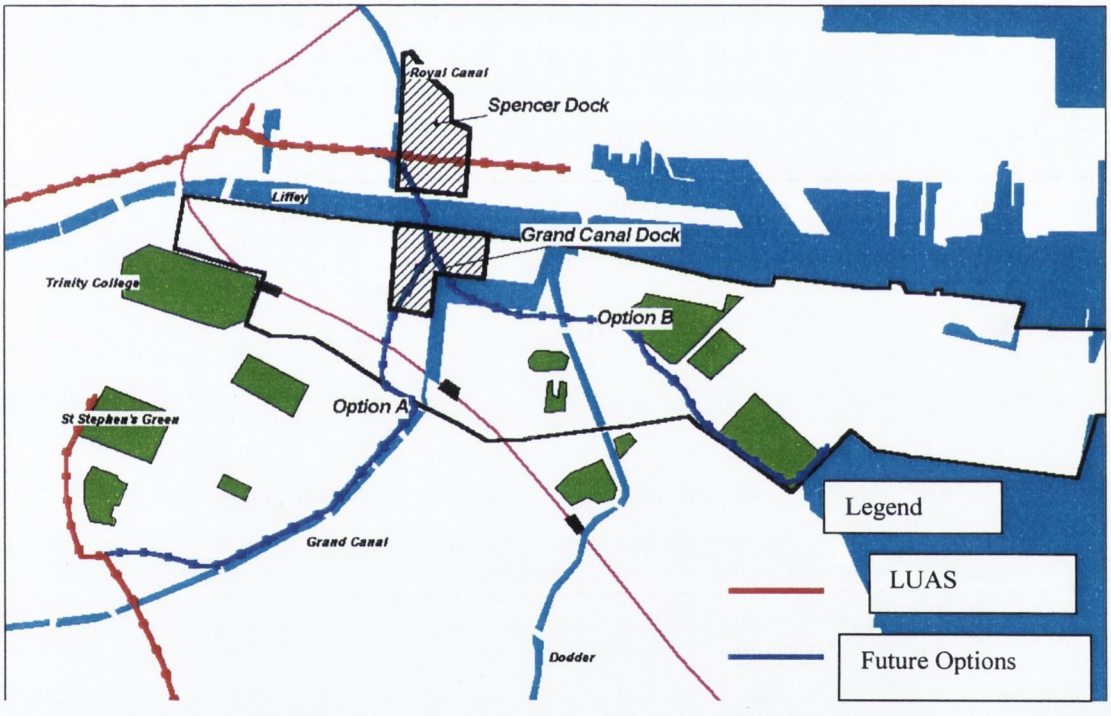

Figure 6.10: Principal Options

Within these two options a number of variations of alignment are suggested. The two principal options are shown in Figure 6.10 and are:

- ***Option A – Grand Canal Link:*** this route would provide a link between the Connolly Station, the IFSC, the Dundrum LUAS line and the south city centre.

- ***Option B – Irishtown:*** this route is a spur from the north docklands through Ringsend, Irishtown with a terminus on South Bank Road.

Option A can only be considered in conjunction with the Macken Street Bridge or the New Wapping Street Bridge. Option B is possible with all three bridge options.

Option A:

Option A is shown in more detail in Figure 6.11 and a description follows. The alignment runs down Macken Street passing under the DART before reaching Grand Canal Street Lower. The DART Bridge on Macken Street (see Figure 6.11), with a central clearance of 4.29m, is one of the highest DART bridges in this Docklands area. If the light rail is to pass to the south of the DART in this area then Macken Street provides the most promising alignment.

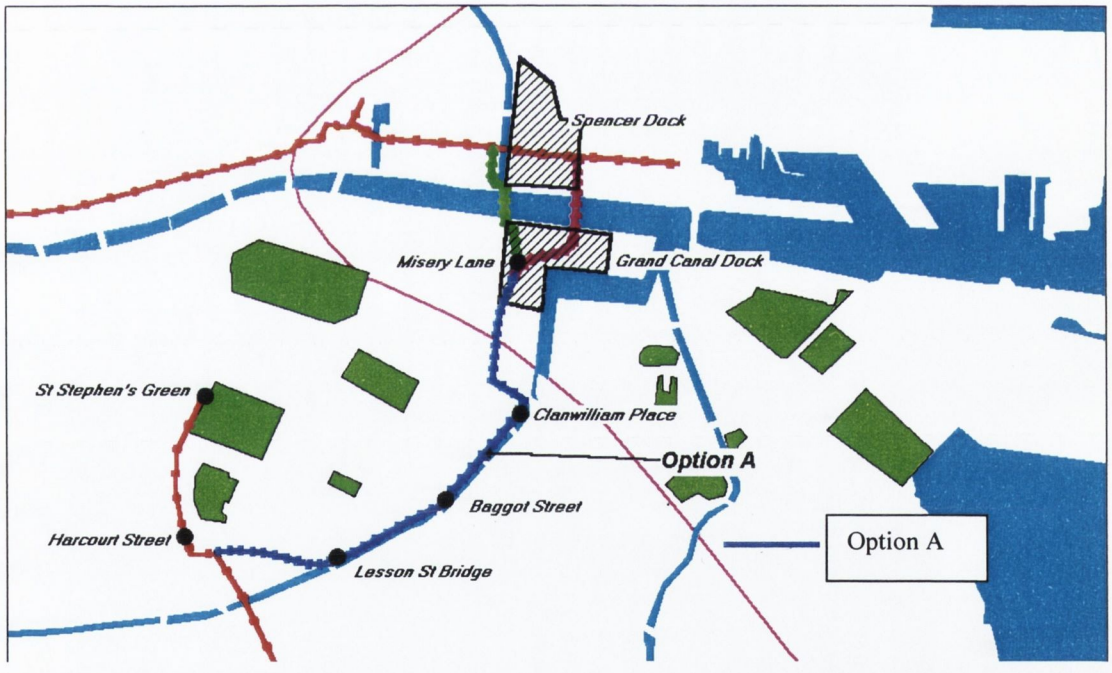

Figure 6.11: Option A

There would still not be sufficient clearance for a light rail line to pass under the current bridge. Remedial work would be required to drop the level of the road in the vicinity of the bridge in a similar manner to that done with the DART bridge over Sheriff Street.

After Macken Street the alignment would turn onto Grand Canal Street Lower for a short distance before turning onto Clanwilliam Place. The route then follows the north side of the Grand Canal as far as Leeson Street Bridge. This section includes Warrington Place, Herbert Place and Wilton Terrace.

Much work has been done by the OPW to preserve the Grand Canal as a conservation area. Replacing the road space with the light rail would enhance this work as it would reduce the impact of the car on the area.

At Leeson Street Bridge the tracks would bear away from the canal and run up Adelaide Road to merge with the Dundrum Line tracks. Initial observations would suggest that it would not be possible to turn directly south onto Peter Place. A tram coming from the Docklands would have to continue onto Harcourt Street. The two possible solutions are:

- Trams would have to reverse at Harcourt Street Station, or
- Trams would run onto St Stephen's Green. People travelling to Dundrum would change at Harcourt Street Station to catch a Dundrum bound train.

Option B:

Figure 6.12 shows the Option B in detail and a description follows. There are a variety of routes by which the light rail could reach Ringsend. Once in Ringsend the best option appears to be for the route to run along the edge of Ringsend Park, along Rope Walk Place. The route then continues along this alignment to Irishtown where it runs between Beach Road and Sean Moore Park. The terminus of the route is at the eastern corner of Sean Moore Park beside South Banks Road.

The alternative routes for reaching Ringsend are termed Option B1, 2 & 3. It is the question of where to bridge the River Dodder and the Grand Canal that poses the problem. Options B1 & 2 would work in conjunction with the Macken Street Bridge or the New Wapping Street Bridge. Option 3 is an alternative arising from the East Link Bridge option. The alternatives are as follows:

- Option B1: Ringsend Road → The alignment turns from Macken Street onto Pearse Street/Ringsend Road. The river and the canal are bridged at Ringsend Road and Bridge Street respectively. This route is just over 3 km long.

- Option B2: Hanover Quay → The alignment runs along Hanover Quay and Britain Quay. The crossing point of the river and canal is between Britain Quay and Thorncastle Street. This bridge would have to be a lifting bridge so that boats could pass between the Liffey and Grand Canal Docks. This route is either 2.8 km or 3 km long depending on which bridge is used for crossing the Liffey.

- Option B3: Thorncastle Street → This option arises from the possibility of bridging the Liffey at the East Link Toll Bridge. It is a short route along Thorncastle Street, Cambridge Street and onto Rope Walk Place. The total length of this route is 2.2 km.

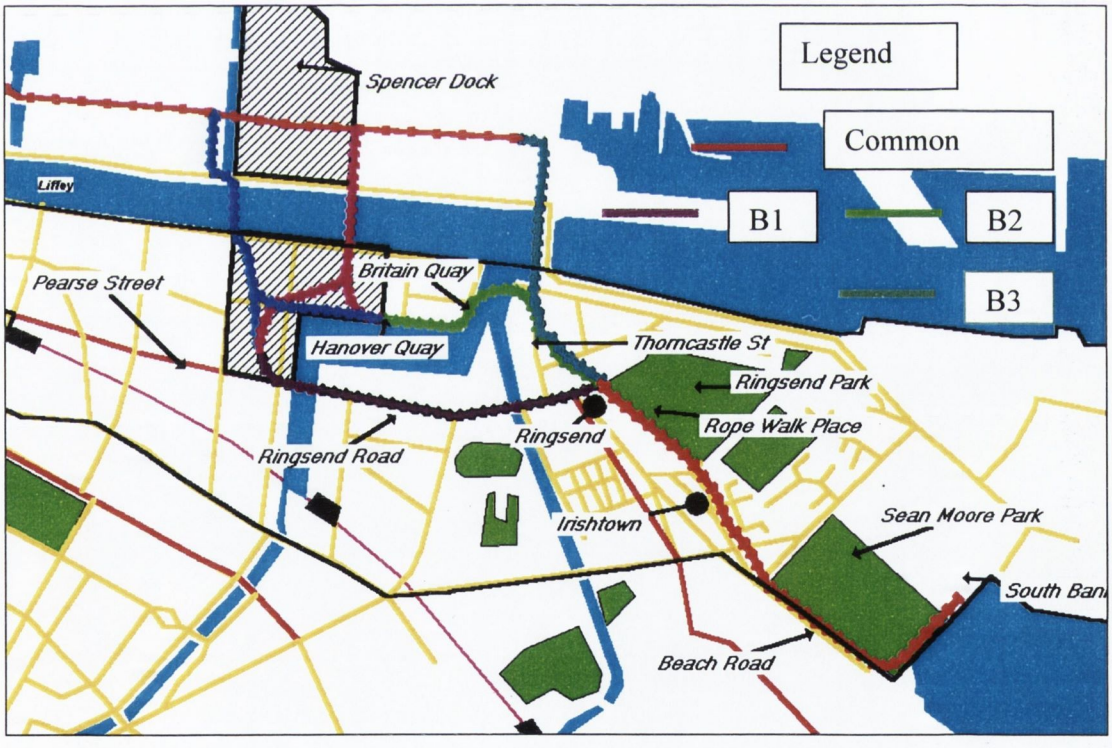

Figure 6.12: Option B

6.5 Future Data Generation

It is necessary to generate future data that will be representative of the growth in the study area. The planned residential developments discussed in section 6.2 will provide the basis for this estimation. Two future year dates are considered, 2006 and 2016, and complete data sets will be generated for each.

The five point process used in section 6.2 is again necessary here but in a slightly different order. The five points are as follows:

1. Compilation of number of origins from each residential area (street or apartment block),

2. Development of matrix of numbers of people corresponding to each permutation of personal characteristics,

3. Car availability data,

4. Allocation of the person matrix into the origin table,

5. Development of trip distribution.

The first step is therefore to calculate the number of origins coming from each of the new developments. This is done in a similar manner as for the base year data (section 6.2 and Appendix 6) and the outcome is shown in Table 6.11.

Table 6.11 shows that by 2006 there will be a large increase in origins from DA South Dock and only a small increase in origins from DA Pembroke West A and Pembroke East A. In summary the additional origins are as follows:

- South Dock: Male 403, Female 408,
- Pembroke West A: Male 48, Female 46,
- Pembroke East A: Male 53, Female 40.

Street Name	***No Units***					***Origins***	
		Adults	***Children***	***Male***	***Female***	***Male***	***Female***
South Dock							
15 Barrow Street	8	12	2	5	7	3	4
7 Hanover Quay	17	25	5	11	14	9	9
98 Pearse Street	5	7	2	3	4	3	3
Barrow Street	135	196	42	89	107	70	70
Dunloe Ewart	231	336	71	153	183	119	120
Green Street East	103	149	32	68	81	53	53
Hardwicke Site	125	182	38	83	99	64	65
Rogerson 1	100	145	31	66	79	51	52
Rogerson 2	10	15	3	7	8	5	5
Rogerson 3	50	73	15	33	40	26	27
Total	784	1140	241	518	622	403	408
Pembroke West A							
South Shelbourne	101	141	31	62	79	48	46
Pembroke East A							
Eastlink Bridge	27	53	18	25	28	18	13
Parkview Place	25	49	17	23	26	17	13
Rope Walk Place 1	23	44	16	20	24	15	12
Rope Walk Place 2	3	7	2	3	4	3	2
Total	75	153	53	71	82	53	40
Total	***960***	***1434***	***325***	***651***	***783***	***504***	***448***

Table 6.11: Origins from New Residential Areas 2000 – 2006

A few large developments are likely to be complete by 2016. Table 6.12 shows the number of residential units and the estimated number of male and female origins that will result.

Street Name	*No Units*					*Origins*	
		Adults	*Children*	*Male*	*Female*	*Male*	*Female*
South Dock							
DDDA Gas Board	1000	1452	308	662	790	516	518
Bolands	70	101	22	46	55	36	36
Total	*1070*	*1553*	*330*	*708*	*845*	*552*	*554*
Pembroke West A							
Zoe	630	878	193	384	494	298	288
Total	***1700***	***2431***	***523***	***1092***	***1339***	***850***	***842***

Table 6.12: Origins from New Residential Areas 2006 – 2016.

In summary the new origins from each ward are:

- South Dock: 1,106,
- Pembroke West A: 634.

This means that the total number of origins from both of these wards is considerably higher than in 2000 and 2006. The total number of origins from each ward is shown in Table 6.13. It can be seen that the largest increase occurs in DA South Dock where there will be 3,115 origins in 2016 compared to the 1,198 in 2000. A sizable increase of almost 700 occurs in DA Pembroke West A whilst there are only 100 more origins in Pembroke East A by 2016.

	DA South Dock	*DA Pembroke West A*	*Pembroke East A*
2000	1,198	1,191	2,153
2006	2,009	1,285	2,246
2016	3,115	1,871	2,246

Table 6.13: Total Origins from each Ward

The next step is to develop matrices of personal characteristics for these new origins. As in section 6.2, Table 6.3 is used as a basis from which to expand out data for new

apartments in the study area. Table 6.14 shows the matrix for the new apartments in DA South Dock by 2006. This matrix will be added to the 2000 apartment matrix for that ward.

Adults	Y		Y		N		N	
Children	Y		N		Y		N	
Male or Female	M	F	M	F	M	F	M	F
< 25	14	9	117	134	4	0	5	0
25 - 34	18	18	350	373	9	9	54	51
35 - 44	5	9	36	32	0	9	22	18
45 - 54	4	5	13	9	0	0	18	5
55 - 64	0	0	0	0	0	0	4	0
> 65	0	0	0	0	0	0	0	0
Total	***41***	***41***	***516***	***548***	***13***	***18***	***103***	***74***

Table 6.14: New Apartment Origins 2006 in DA South Dock.

The proportion of commuters with a car available in the morning peak will be an increasing statistic as the level of car ownership continues to increase. With reference to the rate of increase in car ownership shown in Table 3.5 it was decided to apply half of that rate of increase to the proportion of commuters with a car available. Table 6.15 shows predicted levels of car availability amongst the morning peak commuters from the study area.

These car availability proportions are then applied to the complete origin tables to provide the four matrices as in the data for the base year:

- Car Available Apartment Matrix,
- Car Not Available Apartment Matrix,
- Car Available House Matrix,
- Car Not Available House Matrix.

Ward	*2000*	*2006*	*2016*
South Dock	59 %	65 %	75 %
Pembroke West A	68 %	74 %	84 %
Pembroke East A	79 %	85 %	95 %
Average	69 %	75 %	85 %

Table 6.15: Future Car Availability Amongst Commuters.

These matrices are then applied randomly, in a similar manner as for the base year, to the tables of houses and apartments. The distribution is done for 2006 and 2016 using the gravity distribution model again. The origin data for the relevant year is as developed in this section whilst the destination numbers are based on figures provided by the DTO (1996)

Parking availability was surveyed at 35% of trips to the city centre for the base year. It is assumed that the level of parking availability in the city centre will not be allowed to increase greatly. As a base point, the level of parking is fixed at numerically the same as for the year 2000. The proportion of trips to the city centre with parking available therefore reduces as follows:

- 2006 → 27%,
- 2016 → 24%.

6.6 Public Transport Options into model

Light rail options are included in the decision process in a similar manner to the way the other public transport modes are. The first inclusion is of the base light rail network which is planned to be completed by 2003. This includes the Dundrum line and the Tallaght line. It is also assumed that the extension through the north docks will be complete by 2006 and so it is included in the base LRT scheme. None of these lines actually pass through the study area but is assumed that people could use a connecting bus or travel by DART to reach the nearest convenient station. This combination option is termed LUAS and is compared with the other public transport possibilities for

a particular origin destination trip. The decision is again based on the overall travel time.

Availability of LUAS at the origin is determined by catchment areas. Catchment defined by a 500m buffer zone are drawn around the light rail stops and any residences within these catchment areas are said to have light rail available to them. The catchment area for option A is shown in Figure 6.13 and extends over the westerly section of the study area. As described previously option A provides a link between the two original LUAS lines. Possible destinations are determined by where the complete LUAS network serves. Travel times and service frequencies are calculated in the same way as for DART and bus (section 5.6). The option of travelling by LUAS is then compared with travelling by bus or DART (if available). The best option is selected from the available public transport modes by choosing the one with the quickest travel time.

The catchment of the three B options are shown in figures 6.14 – 6.16. These catchments are used to provide information for the origin database tables but comparing the three figures is also informative. It can be seen visually that option B1 has the largest catchment area. This means that it has the potential to cause the biggest shift towards using LUAS to travel to work in the morning.

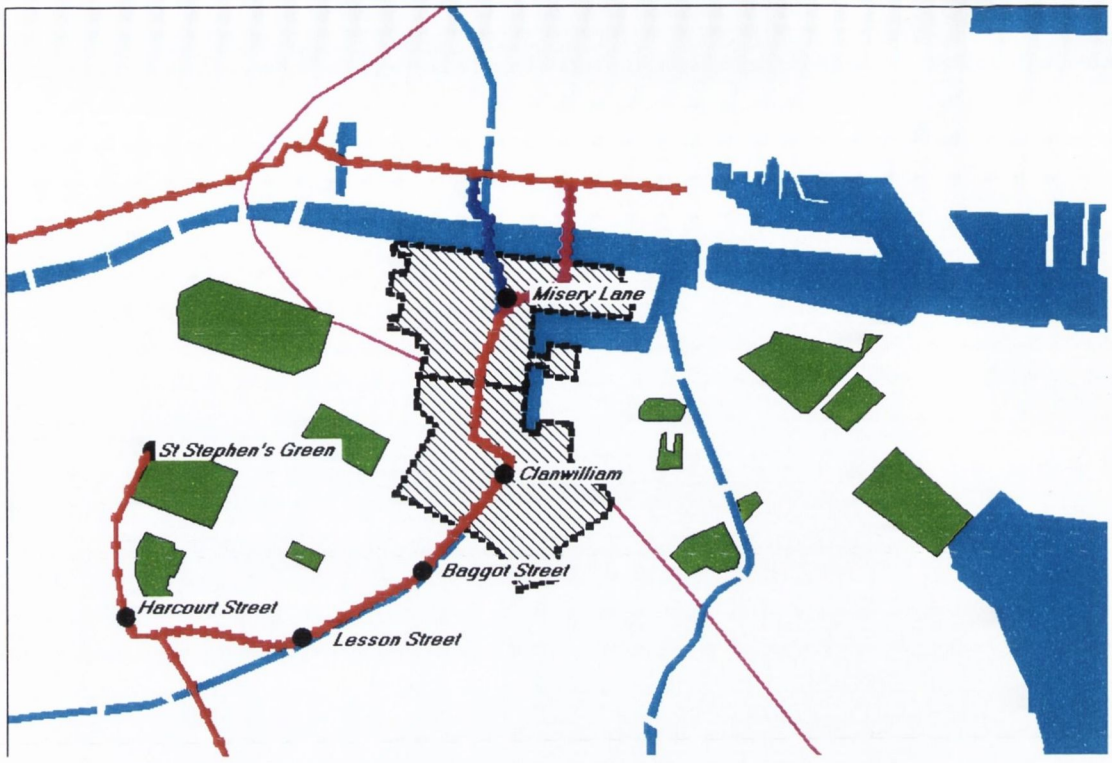

Figure 6.13: Catchment of Option A in study area.

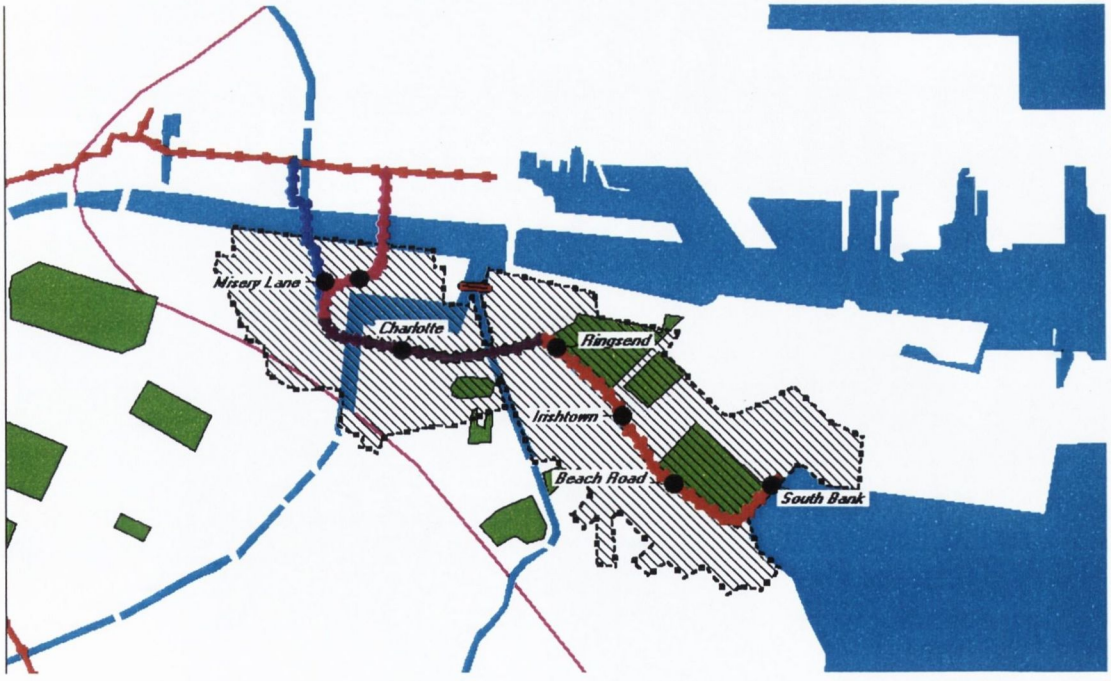

Figure 6.14: Catchment of Option B1.

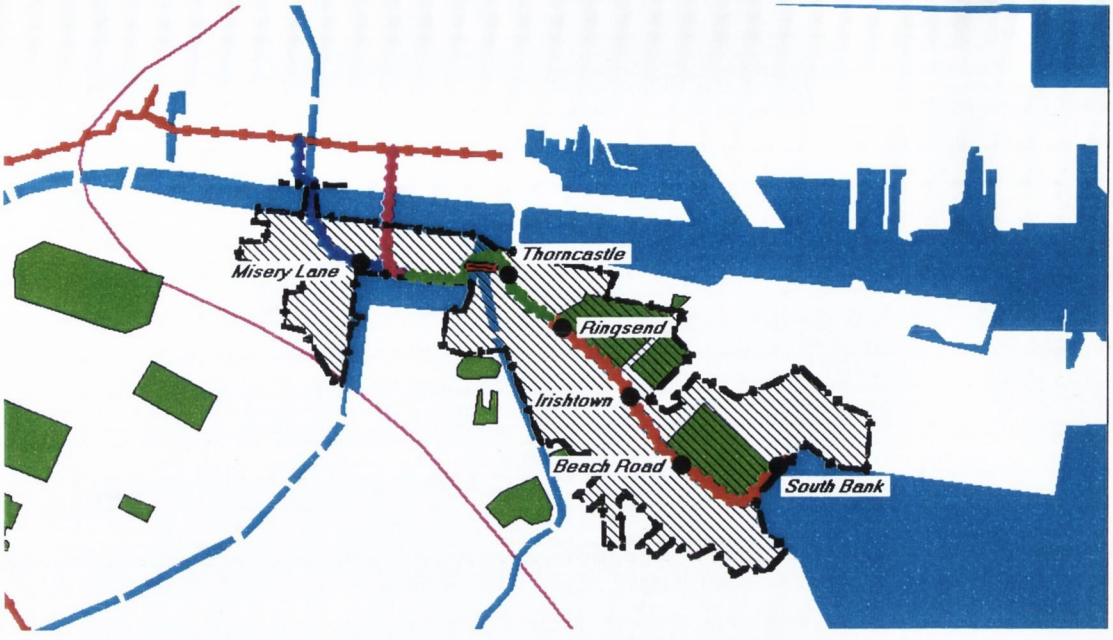

Figure 6.15: Catchment of Option B2.

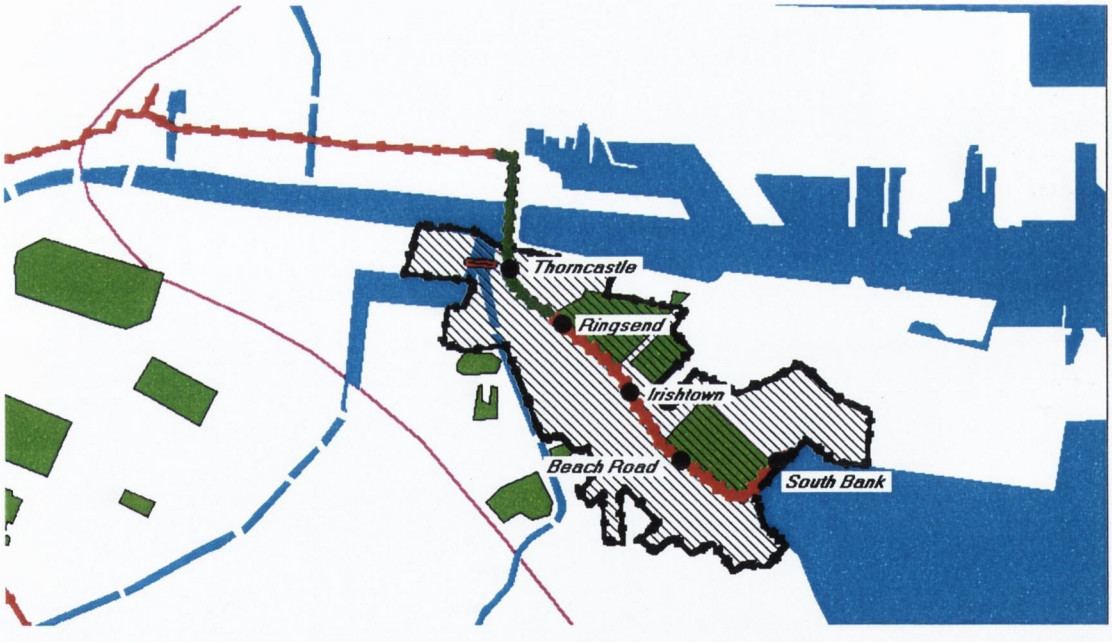

Figure 6.16: Catchment of Option B3.

6.7 Testing Runs

The network configuration chosen in chapter 5, 'AA', is tested for the base and future year scenarios. This is necessary to find out whether the information being input is allowing the network to produce logical outputs for the different scenarios.

Table 6.16 shows the base year and two 2006 test scenarios. The key differences between the two 2006 tests is that, in the first one, there is no LUAS network included. In the second both light rail options, A and B, are available to the trip makers. According to the model 576 people would use light rail to travel to their work destination. A transfer to use this new mode would be expected and in this regard the model is working as expected. A reduction in the use of DART (143 → 91) and bus (344 → 213) occurs as those who wish to use public transport find a more efficient option available to them.

	2000		*2006*		*2006*	
Grand Canal Station	Yes		Yes		Yes	
LUAS	No		No		AB1	
Car	2,183	48%	2,865	52%	3,173	57%
DART	143	3%	143	3%	91	2%
Bus	360	8%	344	6%	213	4%
Cycle	510	11%	465	8%	441	8%
Walk	1,346	30%	1,723	31%	1,046	19%
LUAS	0	0%	0	0%	576	10%
Total	*4,542*	*100%*	*5,540*	*100%*	*5,540*	*100%*

Table 6.16: Version AA

A reduction in walking would also be expected as those who didn't have a public transport option available to them may now have one. The reduction that occurs though is from 1,723 to 1,046 which is 677 people. This is considerably greater than the number travelling by LUAS.

A reduction in car use would also be expected, but instead there is an increase in car use from 2,865 people to 3,173 people. This is an increase from a mode share of 52% to 57%. In the final scenario versions the car travel times will be adjusted to take account of the restrictions on car travel in the area that will be necessary to implement the LUAS. The car travel times are not adjusted at this stage so that the effect of the addition of an additional public transport option can be investigated in isolation.

It is illogical that providing an additional public transport option would increase car use and reduce walking to the extent that is shown in Table 6.16. This outcome suggests that the neural network is not training as expected and is attaching incorrect significance to certain inputs. It would appear that the improved public transport inputs are causing a shift from walking to car use. Another series of tests are run with the form and number of public transport inputs varied so as to investigate their effect.

There are 5 public transport inputs included in version AA: time, frequency, walking distance, PTMT and interchange. The time variable is fundamental to the decision and so it remains unchanged in these tests. The first series of tests is conducted by removing each of the ancillary public transport inputs individually. In each case a comparison is made between the year 2006 with LUAS and without LUAS. It is assumed that when LUAS is available all other modes would decrease to some degree but definitely would not increase. The outcomes of these runs are shown in Table 6.17 labeled TA – TD.

In TA, with the input PT Frequency removed, the expected trend of decreasing car use occurs and LUAS achieves a 13% mode share. An unexpected shift occurs though, as there is an increase from 10.4% to 14.2% in the proportion using a bicycle to travel to work. This is illogical and so there are still some erroneous network links being made during the training process.

In TB, with the input walking distance removed, car use increases from 51.2% to 64.1% and LUAS only achieves a 2.7% mode share. TC reverses the car use trend with a reduction from 48.2% to 41.6% but cycle use almost doubles its mode share. Only

0.7% of people travel by DART, which is considerably less than expected. TD performs well in all modes except cycle. Cycle use increases from 11.9% to 17.4%.

	TA		*TB*		*TC*		*TD*	
Removed Input	*P T Frequency*		*Walking Distance*		*PTMT*		*Interchange necessary*	
Train	99%		98%		98%		98%	
Predict	66%		65%		63%		63%	
Accuracy	1.11		0.77		1.44		1.44	
LUAS	No	Yes	No	Yes	No	Yes	No	Yes
Car	54.7%	52.6%	51.2%	64.1%	48.2%	41.6%	47.3%	41.9%
DART	2.5%	1.5%	1.8%	1.1%	0.7%	0.6%	1.4%	0.9%
Bus	10.6%	4.5%	4.1%	2.2%	4.4%	2.4%	4.2%	2.3%
Cycle	10.4%	14.2%	10.2%	9.5%	16.1%	30.1%	11.9%	17.4%
Walk	21.9%	14.3%	32.7%	20.4%	30.6%	22.0%	35.2%	31.6%
LUAS	0.0%	13.0%	0.0%	2.7%	0.0%	3.4%	0.0%	5.8%

Table 6.17: Test runs of Version AA without the listed input.

The key observations from the 4 test runs are as follows:

- TA → car use decreases, LUAS performs well, small shift towards cycle,
- TB → car uses increase considerably, walk goes down and little LUAS use,
- TC → car use decreases, large shift towards cycling and little LUAS use,
- TD → same trends as TC but closer to expected.

It appears that the test run TA performed the best. A second series of tests is run with TA as the basis – all have P T Frequency removed. The variables removed for these runs are shown along with the outcomes in Table 6.18. The proportion trained correctly reduces slightly for versions TE – TH compared to TA – TD due to the reduction in input variables. TE shows an increased level of prediction accuracy with

69% predicted correctly compared to 63% – 66% for all of the other test runs. The accuracy measure is also a reasonable 1.28. TG and TH are both dismissed due to increasing car and cycle use contrary to logical expectations.

TE and TF have similar trends of mode changes when LUAS is made available. TE being the more accurate model predicts a higher level of public transport use. Car use decreases by just over 2% points. DART, bus and walking all show small decreases and there is an 8.7% mode share for LUAS. This is consistent with a shift from these modes to use the new public transport services. The only problem with TE is that there is a 1% point increase in the numbers cycling.

	TE		*TF*		*TG*		*TH*	
Removed Input(s)	*Walking Distance*		*PTMT*		*Interchange necessary*		*Interchange necessary, Walking Distance*	
Train	96%		97%		97%		97%	
Predict	69%		66%		64%		63%	
Accuracy	1.28		2.16		1.49		2.60	
LUAS	No	Yes	No	Yes	No	Yes	No	Yes
Car	54.6%	52.7%	52.0%	50.5%	52.6%	56.8%	52.9%	57.4%
DART	2.0%	1.2%	0.9%	0.8%	1.0%	0.8%	1.8%	1.1%
Bus	8.3%	3.4%	4.3%	2.5%	4.1%	2.4%	9.9%	5.1%
Cycle	10.3%	11.4%	11.9%	16.0%	9.0%	11.4%	3.1%	6.7%
Walk	24.8%	22.6%	30.9%	26.7%	33.4%	24.4%	32.3%	20.5%
LUAS	0.0%	8.7%	0.0%	3.5%	0.0%	4.2%	0.0%	9.2%

Table 6.18: Further test runs

The network seems to find it difficult to find information in the data to distinguish between whether people will choose to walk or cycle. It is decided to merge the walk and cycle outputs into one output called "cycle/walk". A network is formulated that

has only 3 outputs: car, public transport, and cycle/walk. The input variable for cycle time is removed and the cycle/walk mode is represented by walk time.

The first test version is based on the version with public transport frequency and walking distance removed. This contains the following inputs and is called version TI:

- Car time,
- P T time,
- Walk time,
- Car available,
- Car parking,
- Sex,
- Age,
- Children,
- Adults,
- Apartment,
- Distance,
- PTMT,
- Interchange.

The outcome for version TI is shown in Table 6.19. The proportion predicted correctly is shown as 72%, which is better than achieved with the previous model format. There is a shift away from DART, bus and cycle/walk towards LUAS with 7.2% of people choosing to travel by LUAS. Cycle/walk decreases from 37.8% to 31.5%. This trend can also be seen in the percentage at the bottom of Table 6.19 where the three public transport modes are combined showing an increase from 7.4% to 11.1%. It would be expected that the overall public transport share will increase with LUAS available, even though there will be a reduction in bus and DART use.

Simultaneously but contrary to expectations car use increases from 54.8% to 57.4%. This suggests that the public transport inputs are still impacting car use. There is need for the public transport to provide a clearer indication to the network whether public transport is available or not. The inputs in version TJ are changed so as to do this. The PTMT input is changed from its numerical value representation of different modes to a boolean (yes/no) input for public transport availability.

	TI		*TJ*		*TK*	
Train	98%		97%		97%	
Predict	72%		76%		74%	
Accuracy	1.58		1.44		1.19	
LUAS	No	AB1	No	AB1	No	AB1
Car	54.8%	57.4%	48.1%	45.9%	52.2%	51.8%
DART	1.5%	1.0%	0.8%	0.6%	1.8%	1.0%
Bus	5.8%	2.9%	7.1%	3.7%	5.1%	2.6%
Cycle/Walk	37.8%	31.5%	43.9%	46.4%	40.9%	35.1%
LUAS	0.0%	7.2%	0.0%	3.4%	0.0%	9.5%
P T	7.4%	11.1%	7.9%	7.9%	6.9%	13.1%

Table 6.19: Test runs on reduced output format.

With reference to Table 6.19 for the outcome of version TJ it is shown that the proportion predicted correctly improves to 76% from TI's 72%. The accuracy also improves to 1.44 from 1.58. Car use decreases from 48.1% of the origins to just under 45.9%. The proportion using cycle/walk increases instead of the proportion using public transport increasing. There is very little shift towards LUAS. The public transport options are still not defined clearly for the network.

It is felt that the full PTMT input is necessary to help differentiate between the different public transport modes. TK uses the PTMT input and the interchange variable is replaced with a boolean (yes/no) input for public transport availability. Table 6.19 shows that the proportion predicted correctly reduces slightly to 74% but the accuracy measure improves to 1.19.

Table 6.19 shows that in version TK the proportion who travel by car reduces slightly from 52.2% to 51.8%. DART, bus and cycle/walk all reduce as well to provide the 9.5% mode share for LUAS. As expected the overall proportion of public transport use increases. This increase is from 6.9% to 13.1%. This version fulfills the expected trends for this test. Version TK is taken into the next section for another series of tests.

6.8 Sensitivity Tests

A trained network of version TK was used to perform some sensitivity tests. This network took 5,500 iterations to train and has the following performance related characteristics:

- Trained correctly: 96%,
- Predicted correctly: 77%,
- Accuracy: 0.68.

DTO (1996) data does not consider walking or cycling as a full mode and so it is not possible to validate the complete mode distribution. To make comparisons between the DTO data and that produced by this model it is necessary to reduce the mode distribution here to a car/public transport split. In 1991 the proportion of people travelling by car in the peak period in Dublin was 64% (DTO, 2000a). By 1996 the DTO data (1996) for the study area shows the following mode split between car and public transport:

- Car 71.0%,
- Public transport 29.0%.

The mode choice model developed in this work estimates that the mode split for the whole study area in 2000 would have been:

- Car 82.0%,

- Public transport 18.0%.

This suggests that car use has increased in the 4 years since 1996 to the detriment of public transport patronage. It is likely that such a trend will continue unless additional policies complementary to public transport are introduced. It is important to test how the network will handle the changes in the relevant variables. Table 6.20 shows a series of sensitivity tests run on the 2000 version of the model. The following environmentally friendly adjustments are tested individually and in combinations:

- average speed of car journeys in the city centre and inner suburban areas,
- availability of car parking in the city centre,
- availability of the new DART station at Grand Canal Dock.

	Base	*S1*	*S2*	*S3*	*S4*	*S5*	*S6*
Car Speed (%)	–	-50	–	–	-50	–	-50
Parking (%)	–	–	-50	-100	-100	–	-50
G.C. DART	No	No	No	No	No	Yes	Yes
Car	45.2%	42.1%	41.7%	38.3%	34.4%	44.8%	38.4%
DART	0.9%	1.1%	0.9%	1.0%	1.3%	1.8%	2.5%
Bus	9.1%	9.9%	9.4%	9.7%	11.3%	8.5%	9.8%
Cycle/Walk	44.8%	46.8%	48.0%	51.1%	53.0%	44.9%	49.3%
P T (%)	10.0%	11.0%	10.3%	10.7%	12.6%	10.3%	12.3%

Table 6.20: Sensitivity Tests → environmentally friendly policies.

S1 in Table 6.20 shows the outputs produced when the average speed of car journeys in the city centre and inner suburban areas is halved. Car use decreases from 45.2% to 42.1% with both public transport and cycle/walk increasing. S2 and S3 show the outputs produced when free city centre car parking is halved (50%) and totally removed (100%) respectively. Car use is decreased in both cases with 38.7% of people travelling by car when all of the free city centre car parking is removed.

The speed and parking adjustments made in S1 and S3 are combined in S4 giving a further reduction in car use. Car use decreases to 38.3% with public transport increasing to 12.6% and cycle/walk increasing to 53.0%.

S5 shows the effect of opening Grand Canal DART Station. The effect is small overall with car use decreasing by 0.4 percentage points and public transport use increasing by 0.3 percentage points. When the opening is combined with S1 speed adjustment and S2 parking adjustment then the effect is noticeable and is shown in S6. Public transport use increases to 12.3% of trips, car use decreases to 38.4% and cycle/walk increases to 49.3%.

These tests show that the adjustments made produce logical and noticeable changes to the mode choice outputs. This shows that the network is capable of processing these adjustments in the expected manner. A further 4 tests are run to check how the outputs will change if a pro-car policy was followed. It is expected that car use should increase if within the central area the average car speed was increased and/or car parking availability increased. Table 6.21 show the outcomes of these tests.

	Base	*S7*	*S8*	*S9*
Car Speed	–	–	×2	×2
Parking (%)	–	50		50
G.C. DART	No	No	No	No
Car	45.2%	48.4%	46.9%	50.2%
DART	0.9%	0.7%	0.8%	0.7%
Bus	9.1%	8.8%	9.1%	8.8%
Cycle/Walk	44.8%	42.1%	43.1%	40.3%
P T (%)	10.0%	9.5%	10.0%	9.5%

Table 6.21: Sensitivity tests → pro-car policy.

The test run S7 shows the results when the level of parking available in the city centre is increased. The result is as expected in that car use increases and the use of public transport and cycle/walk decreases. S8 shows that by doubling the average travel speed

of journeys to city centre and inner suburban areas a similar trend of increasing car use occurs. Combining S7 and S8 produces a result, shown in S9, which shows a further increase in car use to 50.2%. The combination produces the lowest level of cycle/walk at just over 40%. Interestingly the pro-car policy has only a small impact on the level of public transport use.

These sensitivity tests suggest that even relatively drastic complementary measures fail to impact greatly on car use. It shows how difficult it is to create a situation where people are less car dependent for their trip to work in the morning. A principal reason why car use can not decrease further is the number of workplace destinations which are not within the central area and so are not affected by city centre car restrictions.

6.9 Summary and Discussion

The survey data is expanded out to encompass the whole of the study area using Central Statistic Office demographic data and Thoms street directory (Thom's, 2000). All of the assumptions and methodologies required are outlined in detail. The end result is a complete set of data for each individual and their work trip for the whole study area in 2000.

The future development of the area is investigated through the distinct sectors devised by the DDDA. There are different development objectives for these areas and these objectives were compared with the plans that are currently being processed. It is clear that the most significant development area will be the Grand Canal Docks area where large scale mixed developments will take place. These developments and developments in the rest of the area are quantified so that estimates can be made for future trip generation. Individual data is then generated for the future scenarios based on two future years 2006 and 2016.

Additional public transport proposals were developed to enhance the planned transport developments planned for the area. A number of options were proposed that can be tested using the mode choice model.

A series of tests were run to check how the network reacts when additional public transport options are available. A 'do nothing' 2006 scenario was compared with a 2006 scenario with a complete LRT extension comprising options A and B. There is an immediate transfer to light rail, but primarily from those who previously walked. This would be expected, but what is not expected is the additional transfer from walking to car use. It was concluded that there was a problem with the training of the network. The network did not have the ability to recognise the improved public transport inputs as being solely related to public transport.

A further series of tests were run with different combinations of inputs relating to public transport. Though improvements were found, a problem arose in that when LUAS was added the network was transferring trips between walking and cycling. This was also considered illogical and it was decided that model performance would benefit from merging the walk and cycle outputs into one output called "cycle/walk". This immediately resulted in improved predictive abilities. The final version called TK, predicted 74% of the test data correctly. This is a significant improvement over the 68% predicted correctly by version AA in chapter 5.

This version shows a logical set of transfers to LUAS when implemented. The input list for TK is as follows:

Car time, public transport time, walk time,

car available, car parking,

sex, age, children, adults,

apartment, distance,

PTMT, and public transport availability.

Having successful calibrated the model to cater for new public transport extensions the next stage was to test the sensitivity of the model to complementary policy options. Two key tools were varied, car travel speed and availability of city centre parking.

These tools were tested in environmentally friendly policies and pro-car policies. The results show that the mode shares varied in the expected directions under these policies.

The sensitivity tests suggest that a shift away from car use to public transport and cycling or walking can be achieved but the fundamental issue that limits this is workplace location. Where workplaces are dispersed over a wide area instead of concentrated in a central location then it is difficult for people to use any other mode than the car. Some 45% of workplace destinations are located outside of the city centre and as a result those people are mostly restricted to travelling to work by car. They are also unaffected by the policy changes. This means that the potential impact of such policies is limited whilst such dispersed travel patterns are allowed to develop.

Through these calibration and testing phases a mode choice model has been developed that will be used to evaluate future scenarios in chapter 7. The novel aspects of this model have allowed some improvements to be made over conventional models. Its disaggregate approach means that each individual trip has been modelled rather than modelling aggregate population segments. It also means that a greater number of explanatory variables can be utilised in the decision processes.

The two final inputs 'PTMT' and 'public transport availability' enable a clear indication of whether public transport is an option for a trip and whether it is rail based or bus based. These two inputs along with the 'public transport time' input enable public transport to be modelled on an equal basis with car traffic. It has been shown that these inputs can be varied to represent different levels of public transport availability. As a result this model can be used to test the benefits of different public transport route options.

Disaggregate models can be transferred and applied to different locations. It is suggested that this would be true for this neural network model as well. The GIS portion of the model would be developed for a new location within Dublin along with the trip matrix for that area. The trained network could then be used to find the modal split for the new area. This means that once detailed data had been collected for one study area then the model would be accurately trained and potentially could be applied

throughout. The extent to which the model could be transferred must be limited by cultural factors. It would probably be necessary to retrain the model on new data if transferring to a different city or country.

Chapter 7

Future Scenarios

7.1 Development of Scenarios

The DTO use two future dates, 2006 and 2016, for future scenarios. Data has been developed for these two dates according to the projected level of development in the area. Scenarios are compiled for these future dates by aligning them with different levels of public transport provision and policy direction.

The 'do nothing' scenario is assumed to consist of the following:

- LUAS → Dundrum line, Tallaght line and extension to north docklands as shown in Figure 6.6,
- Macken Street bridge completed by 2006,
- Grand Canal DART Station included in 2006 scenario[19],
- Car availability as projected for future years,
- Car parking availability at similar levels to 2000,
- Car restraint measures at similar levels to 2000.

The scenarios are based on which of the light rail extensions are implemented. As Table 7.1 shows neither extension is in place in the 'do nothing' scenario. Scenario B and C will have three variants, to cater for the three route B options to be tested.

The following policy issues can also be tested on the scenarios:

- Car Parking availability +/–,
- Car restraint +/–,

[19] Grand Canal DART Station opened in 2000 but after survey date.

A further scenario called "High Density" is used to test how the use of transport might change with increased population densities. These increased densities would be focused in public transport catchment areas.

In terms of urban development this testing process will focus on the successful fulfillment of the last two development objectives, reducing car dependency and increasing the use of environmentally friendly modes. The first objective of reducing trip distances is determined directly by the trip distribution model, which is based on the expected continued dispersal of development through the GDA. Even though some trip distances will reduce as a result of the development policies being applied in the study area, this improvement will be counteracted by the growing number of people who will commute longer distances to the dispersed workplaces. These people will benefit from attractive travel times as they will be travelling in the opposite direction to the majority of the traffic.

The second objective of reducing the number of trips is not applicable in this case study. This work refers to peak morning trips to work and so the only way the number of trips could be reduced is through less people working or more people working from home. Home based work, whilst having environmental benefits, has social and practical problems and its contribution is deemed to be outside the scope of this thesis.

	LRT A	*LRT B*
Do nothing	No	No
Scenario A	Yes	No
Scenario B	No	Yes
Scenario C	Yes	Yes
High Density	Yes	Yes

Table 7.1: Scenarios

7.2 Do Nothing

In the 'do nothing' scenario the transportation changes as outlined above are included but the greatest impact will arise from the growth in population due to the proposed new

developments. In the year 2000 the population of the study area was calculated to be 8,865 and is predicted to rise to 10,624 by 2006 and 13,578 by 2016. This means that there will be an estimated additional 4,700 people in the study area in 2016. This is estimated to result in the peak morning demand rising from 4,500 trips to 7,200 trips, which is an increase of 2,700 trips.

Table 7.2 shows how the mode choice model predicts these trips to be distributed over the modes available. The most significant figure is the rise in mode share of car use from just under 49% to 58%. This of course results in a decline in the share of both public transport and cycle/walk. Public transport's share decreases from 10.7% down to only 5.8%. The use of DART increases to 2.1% by 2006 with the opening of the Grand Canal DART station, but its mode share decreases slightly by 2016. Bus use declines from 9.6% in 2000 to only 3.2% in 2016. A small number use the LUAS network, accessing it either by walking or by a connecting bus.

	2000	*2006*	*2016*
LRT Option		Base	Base
Macken St Bridge	No	Yes	Yes
G.C. DART	No	Yes	Yes
Car	48.8%	52.2%	58.0%
DART	1.1%	2.1%	1.6%
Bus	9.6%	5.2%	3.2%
Cycle/Walk	40.5%	39.0%	36.2%
LRT	0.0%	1.5%	1.0%
P T (%)	10.7%	8.8%	5.8%

Table 7.2: Do Nothing Scenario.

The level of car use increases for a number of reasons. Firstly the level of car availability is predicted to continue to increase over the period up to 2016. This in itself would not allow car use to increase greatly as the availability of city centre car parking should limit the numbers able to commute by car. As shown in section 3.7 the focus of large employment generating developments is now the M50 corridor. This large increase in

destinations in these peripheral areas mean that when they are factored into a distribution model people will be attracted to travel there from the study area. These developments have high quantities of parking spaces available for employees and so this enables people to commute by car.

The increase in population in the study area arising from the new developments will increase the population density. Conclusions were drawn in chapter 2 that increasing population density around public transport stops should increase the use of public transport. The population density around Grand Canal DART station changes as follows:

- 2000 → 82 pph,
- 2006 → 90 pph,
- 2016 → 126 pph.

This means that in 2016 the population density around the DART station will be over the level suggested for a sustainable urban environment. The catchment area of this DART station covers 30% of the study area's population in 2016. The small mode share predicted in Table 7.2 suggests that the increased density has not had any noticeable effect on the use of DART.

The population density on bus corridor A increases slightly over the period up to 2016 as follows:

- 2000 → 60 pph,
- 2006 → 66 pph,
- 2016 → 76 pph.

The figures in Table 7.2 show that bus use declines during this period. This means that the small increase in density does not have any positive impact on the level of bus patronage. It could be argued that the contribution of DART and bus to the public transport mode share would have been even less if the population density had not been

increased. The main observation though is that the changed distribution pattern and the increased car availability has negated any positive impact that the increased population density might have had in creating a sustainable urban environment.

The increased population along with the creation of a mixed use environment results in only a small decrease in the proportion either cycling or walking from 40.5% to 36.2%. The decrease can be attributed to the dispersed travel patterns.

The mode share changes for the future scenarios suggest that the positive impact of small increases in population density can be easily negated through increases in car availability and increasingly dispersed distribution patterns of employment.

7.3 Scenario A

This scenario includes the proposed LRT extension labeled A in Figure 6.10. It provides a vital link between the two base LUAS lines and passes through the edge of the study area. This part of the area contains the Grand Canal Docks redevelopment area, with significant new developments of both residences and offices. As a result, it will provide a public transport alternative for people travelling from the suburbs to a work destination in the south docklands.

Table 7.3 shows the predicted mode outcomes when the LRT extension is added in comparison with the 'do nothing' scenario in grey. It can be seen that the addition of option A improves the public transport proportion by about 2 percentage points in both future years. This only translates to a small decrease in car use accompanied by a small decrease in cycle/walk.

LRT option A as a stand-alone extension improves the public transport share in the study area. It was not expected that it would have a very dramatic effect on the public transport mode share in the area. Its real impact though will be through the following:

- Connecting the two LUAS lines,
- Linking the Dublin 4 office area to the docklands and the city centre.

The second of these points means that people can travel between the office areas during the day for meetings without requiring a car. It is hoped that option A, in conjunction with option B, will provide a comprehensive public transport solution for the area. This will be tested in scenario C.

	2006	*2006*	*2016*	*2016*
LRT Option	Base	A	Base	A
Macken St Bridge	Yes	Yes	Yes	Yes
G.C. DART	Yes	Yes	Yes	Yes
Car	52.2%	51.6%	58.0%	56.8%
DART	2.1%	1.8%	1.6%	1.2%
Bus	5.2%	5.4%	3.2%	3.1%
Cycle/Walk	39.0%	37.7%	36.2%	35.1%
LRT	1.5%	3.5%	1.0%	3.8%
P T (%)	8.8%	10.7%	5.8%	8.1%

Table 7.3: Scenario A with Do Nothing Scenario in grey.

7.4 Scenario B

As Figure 6.10 shows option B stretches right through the study area and so provides service to a large proportion of the population. The three different route options have catchment areas that cover different proportions of the population in 2016 as follows:

- B1 → 82%,
- B2 → 46%,
- B3 → 35%.

This immediately points to B1 having the greatest potential for increasing the level of public transport usage in the area. Table 7.4 show the predicted outcomes for 2006 against the 'do nothing' scenario. Option B1 takes 8.0% of peak morning trips which is significantly above the 6.3% and 4.4% mode shares for options B2 and B3 respectively. Public transport's overall mode share increases by 4 percentage points to 12.8%. Again

the reduction in car use is quite small, with option B1 having a mode share of 50.9% compared with the 'do nothing' 52.2%. The rest of the transfers come from DART, bus and cycle/walk.

	2006	*2006*	*2006*	*2006*
LRT Option	Base	B1	B2	B3
Car	52.2%	50.9%	51.0%	50.5%
DART	2.1%	1.4%	1.5%	1.6%
Bus	5.2%	3.4%	3.8%	4.2%
Cycle/Walk	39.0%	36.3%	37.3%	39.4%
LRT	1.5%	8.0%	6.3%	4.4%
P T (%)	8.8%	12.8%	11.7%	10.2%

Table 7.4: Scenario B 2006.

The figures in Table 7.5 show that the same trends occur in 2016 as in 2006. Public transport's mode share for option B1 increases by 4 percentage points over the 'do nothing' scenario, from 5.8% to 9.7%.

	2016	*2016*	*2016*	*2016*
LRT Option	Base	B1	B2	B3
Car	58.0%	56.1%	57.1%	56.3%
DART	1.6%	1.0%	1.3%	1.3%
Bus	3.2%	2.4%	2.6%	2.7%
Cycle/Walk	36.2%	34.1%	34.3%	36.5%
LRT	1.0%	6.4%	4.7%	3.1%
P T (%)	5.8%	9.7%	8.6%	7.2%

Table 7.5: Scenario B for 2016.

Table 7.6 shows that the population density is greatest along the B1 corridor. In 2000 the densities for all the corridors are around 40 pph. Corridors B2 and B3 show small increases whilst the B1 corridor increases to 65pph. This means that the B1 corridor is

above the 50pph level, which was shown to be critical for increasing public transport use. It also means that in 2016 82% of the population is living at a density of 65pph.

Scenario B therefore clearly shows that option B1 outperforms the other two options. As a result only option B1 will be considered in Scenario C and the "High Density" scenario.

	B1	*B2*	*B3*
2000	44 pph	36 pph	40 pph
2006	52 pph	45 pph	41 pph
2016	65 pph	46 pph	42 pph

Table 7.6: Population Density for year and light rail option.

7.5 Scenario C

Table 7.7 shows the outcomes when the two light rail extensions A and B1 are combined. It can be seen that the public transport share increases by over 5 percentage points in 2006 and 2016. LRT achieves a 10.0% mode share in 2006 which rises to 8.2% in 2016. There is a small shift away from car travel, with a reduction in its mode share of almost 2 percentage points in 2006 and almost 3 percentage points in 2016. The rest of the new LRT trips are transfers from either other public transport modes or cycle/walk.

Combining light rail options A and B1 brings public transport mode share to more than it was in 2000 (10.7%, see Table 7.2). Car use has increased to 55.3% compared to 48.8% in 2000. Some complementary measures are tested to see if the level of car use in 2016 can be reduced. The two measures available are a:

- Reduction in city centre car parking,
- Car restraint resulting in a reduction in city centre car speed.

	2006	*2006*	*2016*	*2016*
LRT Option	Base	AB1	Base	AB1
Car	52.2%	50.3%	58.0%	55.3%
DART	2.1%	1.2%	1.6%	0.9%
Bus	5.2%	3.1%	3.2%	2.1%
Cycle/Walk	39.0%	35.5%	36.2%	33.6%
LRT	1.5%	10.0%	1.0%	8.2%
P T (%)	8.8%	14.2%	5.8%	11.1%

Table 7.7: Scenario C

Table 7.8 shows the predicted outcomes compared against two benchmarking columns. The first column shaded in dark grey is the standard 2016 'do nothing' scenario. The column shaded in light grey is 2016 scenario C. When city centre car parking is reduced by 50% public transport use increases by a further percentage point. Car use decreases by almost 2 percentage points whilst there is a small increase in cycle/walk.

	2016	*2016*	*2016*	*2016*
Car Parking Reduction			50%	50%
City Centre Car Speed Reduction				50%
Car	58.0%	55.3%	53.6%	49.1%
DART	1.6%	0.9%	0.9%	1.0%
Bus	3.2%	2.1%	2.1%	2.3%
Cycle/Walk	36.2%	33.6%	34.3%	37.5%
LRT	1.0%	8.2%	9.1%	10.1%
P T (%)	5.8%	11.1%	12.1%	13.4%

Table 7.8: Testing of Complementary measures.

The final column shows the results when car parking availability is reduced by 50% and car travel speed is reduced by 50% due to car restraint measures. These types of car restraint measures would probably be an inevitable result of implementing light rail in the study area. The scale though of the measures required to achieve a notable change is

quite large. This shows the difficulty in getting people to switch out of their car and also the importance of the relative location between origin and destination.

Public transport use increases further to reach a mode share of 13.4%. LRT achieves a 10.1% mode share. Car use is also reduced to 49.1%, which is only slightly above the car share in 2000. This shows that the provision of high quality public transport provides the opportunity for the public transport mode share to increase. Complementary measures are necessary to maximise this effect and create more of a shift away from car travel towards public transport, cycling and walking.

7.6 High Density

In this scenario the hypothetical situation is tested in which the population density along the B1 corridor is increased to 100 pph. 100 pph is the level suggested in Table 2.1 for a sustainable urban environment. The additional population is located in close proximity to light rail stops along route B1 again fulfilling the conclusions drawn in chapter 2.

Table 7.9 shows the outcomes for this scenario. The first two columns are again used as benchmarks against which the new test runs are compared. The first dark grey column shows the results for scenario C in 2016. The third column shaded in lighter grey is scenario C with the additional complementary measures. A direct comparison of mode shares in the first HD column can be made with the first dark grey column. These columns only differ in population size. In HD the population rises to 19,668 from 13,578. An increase in public transport mode share from 11.1% to 14.4% results. The proportion travelling by car also decreases from 55.3% to 53.7%.

This is an interesting result as an increase in population density around the light rail stops has achieved an increase in the proportion travelling by public transport and a decrease in the proportion travelling by car.

The final column tests HD with the additional complementary measures. This is compared with the relevant 2016 column beside it. The share of public transport rises further to a mode share of 16.7%. This is the highest public transport share achieved in

any of the scenarios. The car use share also decreases to 48.0% which is less than that in the 'do nothing' scenario in 2000. LUAS mode share increases to 11.1% with the additional population focussed around the stops. This further increases to 13.1% with the complementary measures.

	2016	*HD*	*2016*	*HD*
Car Parking Reduction			50%	50%
City Centre Car Speed Reduction			50%	50%
Car	55.3%	53.7%	49.1%	48.0%
DART	0.9%	0.9%	1.0%	1.0%
Bus	2.1%	2.4%	2.3%	2.6%
Cycle/Walk	33.6%	31.9%	37.5%	35.2%
LRT	8.2%	11.1%	10.1%	13.1%
P T (%)	11.1%	14.4%	13.4%	16.7%

Table 7.9: High Density Scenario

This scenario shows that an increase in the proportion using public transport at the expense of the proportion using private car can be achieved by combining the following measures:

- Increasing population density around public transport stops,
- Implementation of quality public transport available to a large proportion of the population,
- Reduction in the level of city centre all-day parking,
- Car restraint measures to allow public transport more priority.

7.7 Comparison of Scenarios

The scenarios have been developed and presented to show the urban development benefits possible through combining public transport and land-use planning. The benefits have been analysed through the changes in mode share for the peak morning trip to work. As a result of the focus of this work, actual numbers travelling on the transport networks in the study area are not presented. It is worth mentioning the type of additional trips that would be found in the area:

- Trips originating outside the study area, but with destinations inside,
- Trips with origins and destinations outside the study area, but passing through the study area during their journey.

These trips could be found on all the modes including public transport. In fact, the new public transport extensions will open up the area for people from all over Dublin to consider the possibility of working in the docklands.

It is interesting to investigate how the LRT network is used by the people in the study area. People can leave the study area on the LRT network at two different gateway points. These two points are shown in Figure 7.1 and labelled as Spencer and Baggot Street. Table 7.10 shows the numbers of people that leave the study area at the two different points. The number of LRT trips that have both their origin and destination within the area are also shown in Table 7.10 and labeled as "Local".

	C	*C* ++	*HD*	*HD* ++
Spencer	291	343	572	648
Baggot Street	198	264	363	453
Local	106	125	246	291

Table 7.10: LRT use in 2016 for Scenario C and "High Density" (++ means that the two complementary measures are added).

It can be seen that a greater number of people leave the study area through Spencer than through Baggot Street. For the standard version of Scenario C (first column Table 7.10)

291 people travel through Spencer, 198 through Baggot Street and there are 106 local LRT trips. The other scenarios show a similar trend in distribution but with an increased number of trip makers. This is maximised in the HD version with complementary policies. 648 people from the study area travel through Spencer with 453 travelling through Baggot Street and 291 local LRT trips.

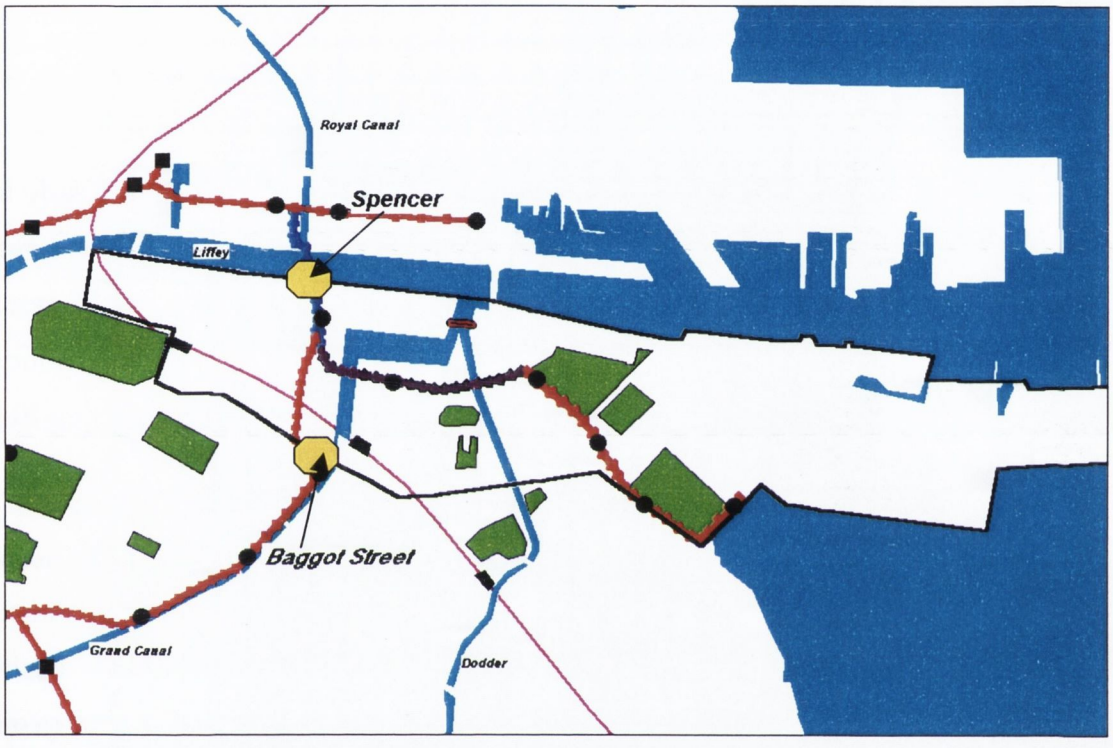

Figure 7.1: LRT gateway points from study area.

The numbers estimated to travel on the LRT system from the study area are well below the guideline figures shown in chapter 2. Due to the short length of this extension it would not be expected that it would carry the same level of passengers as a longer suburban extension. It would be expected that additional patronage would be gained from the residences just to the south of the study area in the area between Irishtown and Sandymount.

As mentioned earlier in this section the system will also cater for a large number of trips coming into the area from the suburbs. This will be vital for the viability of the commercial developments in the area. Such access would not be achieved without the

level of integration possible by extending the LUAS system. In addition the importance of a rail-based service to maximise the positive impact on the development potential of the area can not be ignored. It was shown in chapter 2 that the developers in Salford Quays had no interest in assisting the development of a bus service but contributed financially to the development of an extension to the Metrolink system.

7.8 Summary and Discussion

The scenarios have been developed and presented to show the potential urban development benefits possible through combining public transport and land-use planning. The objectives that are being addressed through this coordination are a reduction in car dependency and an increased use of environmentally friendly modes of travel. The success of this coordination is analysed through the changes in mode share for the peak morning trip to work. It is hoped that the realisation of these objectives will be shown by a shift away from car use to either public transport or the cycle/walk option.

A 'do nothing' scenario was run as a bench mark, for each of the future years, for comparison with the rest of the scenarios. It was shown that by 2016 population increases in the area would result in increased densities around the public transport services. In fact the population density around the new Grand Canal DART station is estimated to be well over the 100 pph suggested for a sustainable urban environment. However the mode share changes for the future years suggested that the positive impact of small increases in population density can be easily negated through increases in car availability and increasingly dispersed distribution patterns.

Scenarios A and B are used to test the individual significance of the two LRT extensions. It was always assumed that Scenario C, the combination of both, would outperform Scenarios A and B. The results show that option A provides a small increase in public transport use with a corresponding reduction in the two other mode options. It is concluded that option A's most significant contribution will be for trips originating outside of the area. This will provide a connection between the two LUAS lines and a public transport path between the Dublin 4 office area and the city centre.

In Scenario B the different route options for extension B are tested and option B1 is selected as being the best as it considerably outperforms the other options in the following areas:

- The catchment area of B1 covers 82% of the population of the study area,
- B1 provides the largest shift towards public transport use,
- The population density of the B1 corridor reaches 65 pph in 2016.

65 pph is above the threshold level of 50 pph which was deemed in chapter 2 to be necessary for improved public transport use levels.

Combining the two public transport options in Scenario C provides a further increase in public transport use. What is found though is that public transport increased its mode share largely at the expense of the cycle/walk option with only a small decrease in the car mode share. This means that the two objectives of reducing car use and increasing the use of environmentally friendly modes are not being achieved. Complementary policies targeting car parking and car travel times within the central area were found to be necessary to create a reduction in car use. It was found that these complementary measures needed to be very stringent to achieve a noticeable change. This was due to the large proportion of trips that had their destination somewhere outside of the central area. In many cases such tripmakers do not have the option of not using their car.

The HD scenario tests the effect of further increasing the population density to over 100 pph in conjunction with the measures already implemented. It shows that the public transport mode share can be increased to a high of almost 17%. It is therefore concluded that all four measures population density, quality public transport, reduction in car parking and car restraint are required to maximise the move towards an urban environment. The extent to which this can be achieved is very dependent on the location of workplace destinations. Non-central workplaces located along a motorway corridor are difficult to serve with public transport and so the private car is generally the only option.

8 Discussion and General Conclusions

8.1 Urban Development Policy

From the outset four objectives were laid down as being necessary to achieve a more sustainable urban environment. These objectives are as follows:

(i) reduction in trip distances,

(ii) reduction in number of trips,

(iii) reduction in car dependency,

(iv) increased use of environmentally friendly modes of travel.

It was concluded from research that urban density was the single most important factor in reducing car use. Residential densities of above 50 pph were deemed to be necessary to reduce car use and increase the use of public transport. These higher residential densities should be concentrated around public transport nodes (preferably rail based). It was also suggested that population densities of greater than 100 pph would lead to an improved urban environment where environmentally friendly modes were used for the majority of trips.

In order for these increased densities to provide benefits, the location of workplace destinations must also be considered. Workplace destinations should be located near central rail stations (for lines with high residential densities) and in mixed land-use areas. In addition the public transport service must be competitive in terms of travel time and consistency of travel times compared to other modes. Complementary environmentally friendly transport policies must also be pursued to extract the maximum benefits from the public transport and land-use plans.

It was determined that though it is a strategic aim of the EU that there should be a move towards embracing sustainable development strategies, it is only through the individual state planning systems that policies are realised. This means that improved urban environments are being achieved with various degrees of success. It was concluded that

the continental model of public transport regulation provided the most potential for an improved urban development.

LRT systems implemented with extensive complementary measures were found to be the most successful. Throughout continental Europe car restraint measures were given top priority along with measures that increased the attractiveness of the public transport service. It was found that land-use planning was coordinated closely with public transport planning throughout The Netherlands.

Redevelopment areas were investigated as these areas have the potential to be more easily developed in a sustainable manner than developed areas. Three redevelopment areas were contrasted and it was found that Amsterdam's integrated and prescriptive manner of development provided the greatest potential for creating an improved urban environment.

Dublin was analysed to see how it has developed and to see where it lies on the path towards sustainability. It was shown that up until 1999 there had been little coordination between land-use and transport planning. This has resulted in new travel patterns being developed through the '90s, which are not consistent with the public transport plans developed in the early '90s. The focus of workplace developments was shown to be along the M50 corridor, creating a situation where the number of car based trips increased and lengthened.

The principal reason that this has been allowed to happen is the inadequacies of the administrative structures for transport and land-use planning. It is the responsibility of the DTO in conjunction with the Department of Public Enterprise to plan public transport in the capital. Meanwhile the Department of the Environment and Local Government in conjunction with the local authorities are responsible for land-use planning. As a result of differing agendas there has been no coordinated approach to planning in Dublin.

New transport plans focus on catering for this increased demand with extensive public transport, but there is no move to reduce trip distances. There is also an attempt to coordinate these plans with the strategic land-use plans for the GDA. Unfortunately these

latest land-use plans for the city do not prescribe population densities sufficiently high enough to provide transportation benefits.

A dedicated development authority is redeveloping the docklands area in Dublin. Due to its close proximity to the city centre and the mixed land-use plans, there is the potential that this area can be redeveloped along sustainable lines. At present some quality public transport is being planned for, but it is not comprehensive enough and this could limit the benefit of the positive land-use aspects. It is part of this area that is used as the study area for testing out some of the policies that have been put forward. To provide the mechanism for testing these policies a novel type of transportation model was developed.

8.2 Neural Network Mode Choice Model

This mode choice model focuses on mode choice and is formulated using a neural network. The policies to be tested seek to reduce car use and increase the use of environmentally friendly modes such as public transport, walking and cycling. It is necessary to be able to model the use of these modes at a detailed level in a manner that has parity with the modeling of car use. The neural network model developed allows the decision process to be considered at a disaggregate level, each individual trip maker is modelled. The inputs to the model consist of the relevant information about the trip and trip maker. The output will be a prediction of the mode used. Quite a large number of explanatory variables can be used to fully represent each trip and trip maker. The combination of a disaggregate model and a large number of explanatory variables enables public transport to be modelled at the same level as the private car.

A unique part of neural networks and hence this mode choice model is that the relationship between inputs and outputs is 'learned' by the network. This means that data with known outputs is repeatedly presented to the model in a 'training' process. The internal weights between layers of the network are adjusted continuously throughout the process until the network is adjudged to have reached convergence. Convergence is where the network settles on a particular solution and returns the same set of results over a number of iterations. The network is then said to be trained and can be presented with new input data from which it can predict outputs.

The data required so that the network can learn was collected through the administration of a questionnaire based survey. This survey provided an interesting insight into the travel characteristics of the study area. It was found that 49% of the peak morning trips to work were made either on foot or by bicycle. This showed the benefits to be gained by having residential areas in close proximity to workplaces. The significance of car availability and parking availability was shown by the statistic that 71% of respondents with both a car and parking available to them drove to work. Another significant finding was that of the DART users, 30% of them had both a car and parking available to them whilst only 14% of bus users did. This suggests that rail based public transport has a greater attraction for car users.

Data on route lengths, public transport routes, origin locations and destination zones was compiled in a GIS application and then exported into a standard database application. This was then queried with the personal data collected through the survey and stored in a form from which the neural network model was coded to extract the necessary information. The form that this information was presented to the model was governed by the aim of providing the neural network model with the ability of being able to distinguish between the range of values for each input.

The shape of the transfer function means that the input data must be scaled to values between '0' and '1'. It was also found that a logarithm scale should be used where input variables had a large range of values. This was suggested in literature and testing confirmed that it was true for this application of a neural network model.

It was found that where data items, like age, were collected in categories it was necessary to condense the information into one input. Giving each category its own input variable results in there being too many inputs compared to the number of data items. Condensing the information into one input means that the network will experience a greater range of input values for each variable. This enables the network to build up a better representation of the link between inputs and outputs. Numerical values between '0' and '1' were assigned to each category with no numerical significance being placed on the

actual values used. These values should be thought of in terms of labels rather than numbers.

Extensive development work was then required to identify the best combination of data inputs and network configuration. Both the pilot study and the development work, with the full mode choice model, showed that the best network configuration was one with 3 layers and where the number of middle layer nodes was equal to the number of input layer nodes. In order to test the network the data set compiled from the survey was split into two parts. The first part was used to train the model and the second to test the model's predictive powers. The first version ran had the following performance statistics:

- Trained Correctly – 70%,
- Predicted Correctly – 61%.

Various combinations of additional inputs were added to see how the performance statistics changed. It was found that progressive addition of new inputs did not necessarily improve the outcomes. In fact some combinations of inputs appeared to cause internal interactions that actually reduced the proportions predicted correctly. This meant that it was necessary to test many different combinations of inputs. An additional performance measure was developed that looks at the individual predicted outcomes for each mode. It gives an indication of whether any particular input configuration produces a bias towards any particular mode outcome. This approach in assessing network performance at individual node output is novel and is considered to be very important for assessing the performance of neural networks with multiple output nodes.

Following this extensive development and testing the final version's performance statistics were:

- Trained Correctly – 97%,
- Predicted Correctly – 74%.

This shows a significant improvement over the initial network. It still means that only three quarters of the test data is being predicted correctly with one quarter incorrect. The principal reason for only achieving a 74% prediction rate is the size of the training data set. The survey achieved a 10% response rate, which means that the model is trained on 6% of the study area. This corresponds to only 185 data members for training. These data items are spread over 11 different input variables with 4 different output modes. A larger training data set would mean that all the different trip permutations were covered. It was suggested that such a training set could be compiled in conjunction with the CSO. This would also mean that the training set could be selected to encompass all of the different personal characteristics. A problem with the survey method is that certain categories of people are more likely to return filled out questionnaires. This could have introduced biases into the training of the model.

The model's final version contains the following inputs:

Car time, public transport time, walk time,

car available, car parking,

sex, age, children, adults,

apartment, distance,

PTMT, and public transport availability.

From these inputs the model can predict for each individual journey, which of the following modes will be chosen:

Car, DART, Bus, LUAS, and Cycle/walk.

8.3 Policy Testing

The model predicted the modal split for the various scenarios based on the study area. The first two scenarios A and B were primarily used to assess the individual benefits of the LRT extensions A and B. The results of Scenario B enabled one of the three route

options to be selected. Scenario C was then used to consider the benefits of combining the two extensions and the future land use patterns with a 'do nothing' scenario.

The provision of the two LRT extensions, in 2016, resulted in an increase in public transport use. The majority of these new public transport users transferred from the cycle/walk option and there was only a small decrease in car use. Two stringent complementary car restraint policies were implemented to achieve a reduction in car use. A limited shift was achieved and the former car users transferred both to public transport and cycle/walk. Stringent policies were required to get a shift because of the large proportion of tripmakers who are restricted to using a car to reach their place of work because of its non-central location. These tripmakers are not impacted by such policies.

Along the B1 LRT corridor the population density was predicted to have risen to 65 pph in 2016. This means that would be in the correct range for encouraging public transport use. The HD scenario showed that by increasing the population density on the B1 LRT corridor to 100 pph the public transport mode share increased further. The results of Scenario C and HD show that steps can be taken towards achieving improved urban development objectives through a coordinated approach to land-use and transportation planning. Two important elements are, increased population density around public transport stops and the provision of high quality public transport for a large proportion of the population. It is also necessary to consider the location of workplace destinations. These workplace destinations should be located around the central rail stations unlike the dispersal of workplace destinations in the GDA. This dispersal is the factor that contributes the most to the high proportion of car use predicted for the future scenarios.

8.4 Future Work

For further use of this neural network mode choice model it would be necessary to improve the percentage of outputs that were predicted correctly. It is felt that a larger training data set should enable a greater accuracy of prediction to be achieved. In mode choice modelling there are always going to be modes with a small overall share. This means that with a small training data set the model is not going to experience a wide

range of input values for that particular mode. Increasing the size of the training data set should increase the range of input data that the mode is trained on for each mode.

Further work could be done on the preparation of the data for inputting into the network. The suitability of the logarithmic scale for scaling the time inputs could be examined by comparing the results when other scales are used. Different transfer functions could also be tried to see if that affected the performance in any way.

Different performance measure could also be tried. These could be coded into the model and the selection process fully automated.

A suggestion for a future application of the model would be to test it on a different study area within Dublin city. It would be necessary to survey the area to compile trip information on the individual tripmakers in the area. The following data would have to be collected for the database: origin and destination, demographics and other personal characteristics. The GIS information would also have to be updated. The trained mode choice neural network would then be applied directly to the area and the outputs compared with mode choice data collected in the survey of the area. This would give an indication of whether the model was transferable or not.

Personal Communications

Peter Black (Metrolink, Manchester), 26/11/98

The main focus of the discussion revolved around the Metrolink extensions through Salford Quays to Eccles. At the time of the meeting a bus service linked the area with Manchester city centre at a ½ hourly frequency. A suggestion was made to the developers that they should finance an enhanced pre-Metrolink bus service. According to Black the developers were not interested in being involved in a bus base service. The developers were willing to provide contributions for the Metrolink extension.

According to Black Metrolink has had success in the privatised bus environment because:

- original passenger base from rail lines,
- speed and frequency,
- competitive with buses.

There will be a 12-min frequency on the route to Eccles. A complex bay platform is being built at Cornbrook.

The Salford Council was involved in fortnightly meetings during the planning of the extension. The Council has allowed the developers to provide parking as they saw fit. This is due to the competition from other areas in England (developments would just go elsewhere if parking were limited). Some of the key office developments have taken place around the proposed route of the line.

Christine Lassalle (Semitan -- Nantes LRT), August 1998.

Semitan has to compete for the concession every 10 years. At present it has 5 years left on its contract. They operate the system and also oversee the building of new extensions.

According to Lassalle the Mayor was very instrumental in getting the first line built. He is now the President of Semitan. He saw it as a vision for the city. He lost his post because people were unhappy with the disruption. The next mayor decided that he had to

continue because so much work had been done even though he was against the scheme. It has been a great success and everybody is supportive now.

The first and second lines were built to link social quarters with the city centre. The first line was easy to build because a lot of the route was alongside a mainline railway. The third line which was under construction in 1998 will replace the no 40 bus. This is a crucial bus route and is very heavily used. It was hoped that this line would have a large patronage immediately.

There was some reduction in road space for private cars to provide space for the tram but it was well organised. The city has a very good orbital route which takes away any of the through traffic. They are also planning extensions to the existing lines. Line 2 will be extended southwards towards the Péripérique and Line 1 will be extended into an industrial area.

Duncan Lyster (Hamilton Osborne King), February 2001.

	2000	*2001*	*2002*
Blackrock		2,323	
Blanchardstown	10,265	3,553	8,370
Central Park		38,186	16,983
Cherrywood		7,739	10,962
City Centre	268	51,401	27,520
Citywest	17,114	19,160	11,845
Clondalkin	3,411		
Crumlin	1,397		
Deansgrange		5,502	
Dundrum		1,911	1,895
Dun Laoghaire	8,361		2,738
East Point	10,779	25,373	3,948
Grand Canal	3,570		44,697
IFSC	28,799		
Kylemore Road	408		
Liffey Valley			12,790
Malahide Road	3,159	3,514	
N City Centre		3,149	
Naas Road		5,774	9,050
Navan Road		9,839	
Parkwest	28,266	31,322	44,830
S City Centre	3,368	16,225	10,016
Sandyford	25,548	37,949	40,501
Santry	3,395	3,782	18,045
SE City Centre		4,963	17,975
Swords	6,317	8,133	
Tallaght	8,495	6,000	1,777
W City Centre	11,549	24,221	25,505
Total	***174,469***	***310,019***	***309,447***

Derry O'Leary (Strategic Manager, Dublin Bus), 24/8/98

O'Leary has had meetings with the DDDA about their proposals for DABS. They discussed the proposals that are outlined in the Master Plan. Dublin Bus were to look at the proposals and get back to the DDDA but at the time of this meeting nothing had happened.

According to O'Leary any system put in place would lose money in its initial stages. Dublin Bus would be looking for the DDDA to fund or at least partially fund the service. He would imagine that mini-buses would service the route initially.

Professor T. Ridley (Imperial College, London) 01/07/98

Reg Ward was Chief Executive of the London Docklands Development Corporation (LDDC) and he had a visionary view of the whole Docklands. He felt that there should be a public transport spine down the length of the development area. This plan was before the conception of Canary Wharf. Tony Ridley was in charge of developing a LRT system for Docklands. Two design points were set down early on:

- the system would make use of disused rail alignments,
- the system would be elevated.

The Docklands Light Railway (DLR) was organised jointly by the Greater London Council (GLC) and the LDDC. The small team that Professor Ridley was leading was facilitating the scheme for these two bodies. It was proposed that the project would cost £65m, which according to Ridley was quite modest in cost. Reg Ward, of LDDC, wanted the system to use new technology and so it was to be automated. The LDDC was providing half of the money and so it could demand this.

The government was not willing to spend large amounts of money on public transport because of the environment at that time. The levels of ridership on London Underground had been dropping steadily for 40 years in the early 1980's. This was the principal reason that a LRT system was being put in and not an underground extension. The DLR

was to be an inexpensive system. The government agreed the proposal and gave them £1m for inflation and it was to be built in a package deal.

In August '82 G. Ware Travelstead, from Manhattan, came into Ridley's office. He wanted to build 10,000 sq. ft of offices on top of the DLR at Canary Wharf. His aim was to create a new city of London in the area. One of his requirements was for Ridley to put a Bill into Parliament to upgrade DLR and extend it into Bank Station. He required a good transport system to link the new area to the City. It was also necessary for the system to have a good image. He was willing to pay for the Bank extension. They managed to get the Bill into Parliament by that November.

The package deal caused problems since they had not managed to get close enough to the final system design in the short period. G. Ware Travelstead could not deliver the money and had to pull out of the scheme. Paul Reichman came in to finish the project.

The DLR did not have enough capacity to help promote more development in the area. There were proposals to extend the Bakerloo line under Canary Wharf. This idea then developed into the Jubilee Line Extension. Paul Reichman wanted to put the JLE higher up the government's agenda. Ridley advised him to put money into it.

Carmel Smith (DDDA), 2/6/98

Smith advised me to contact the Dublin Transportation Office to find out information about the transportation proposals for the Docklands Area.

The rest of the interview concerned what type of developments were likely and what densities would be prescribed. The information supplied has since been superseded by the publication of the "Grand Canal Docks Dublin, Draft Area Action Plan, 1999" (DDDA, 1999) and relevant planning permissions.

Roger Squire (Former Chief Executive LDDC) 01/07/98

The LDDC started special bus routes through the area. They got them going by subsidising them. They were owned by London Transport (LT). As a result of the initial

problems with the DLR the LDDC took on the running of the DLR. They approached it by treating it purely as a computer system. LT had been trying to add more trains to the network because of the unreliability. According to Squire this just exasperated the problem. LDDC began to take trains off the system so that the computer could cope. By doing this they increased the reliability.

The City Airport was created through private investment. There is only a ten minute check in and so you can be in the air a very short time after leaving your office in Canary Wharf. Squire says that the developers of Canary Wharf paid 100% of the Bank extension. They are also contributing to the JLE. Their contribution is to be £400m over 25 years. This works out at £250m npv.

The JLE because of its higher speed will mean that the travel time between the West End and Canary Wharf will be the same as the travel time between the City and Canary Wharf. The travel time between the City and the West End will also be about the same. This creates an equilateral time triangle of the key areas in London.

All the stations on the JLE are individual as they have been designed by different leading British Architects. All the stations will have glass doors along the side of the platform that only open with the doors of the trains. This produces better levels of safety and also stops the rush of air into the stations.

Tony Struthers (Director of Development Services and Deputy Chief Executive, Salford City Council), 26/11/98.

The development is primarily car base and for financial and professional office developments the car parking provision is to be 1-space/3 employees.

The Salford/Trafford Enterprise Zone (EZ) was designated in August, 1981, and encompassed some 150 hectares in Salford. The EZ was intended to last for 10 years until August 1991 and exemption would be provided from Development Land Tax and Council rates, together with 100% capital allowances for commercial and industrial

buildings, simplified planning procedures and controls. The EZs resulted in a lot of speculative office development. This meant that initially there was a high vacancy rate.

Council controlled the redevelopment in Salford. According to Struthers this resulted in a more sympathetic approach to the problems of the overall area. It is felt that locals have stayed in the area even though there has been a 'yuppification'. The Council is working with the community in Oldsall Estate to try and raise the living standards. It was up to the politicians to take the financial and strategic risk.

Ed Tumath (Croydon Tramlink), 14/7/98

In the 1970s the council wanted to create a permanent public transport link between New Addington and Croydon. In the 1980s British Rail was looking to close down or offload its non-profitable rail routes and concentrate on its high capacity radial routes. It was seen that this could be done in Croydon and convert the lines to light rail and so provide the required link. In 1990 the Council was approached and they did a joint feasibility study with London Transport. MVA produced the actual report. The forecast patronage was 25 million trips per year. They expected to get a 10% transfer from car and 60% from buses.

In February 1991 they underwent public consultation on the routes. The Bill was lodged in November 1991. The government stipulated that private money would be required to fund the system. They advertised for a Project Development Group (PDG). The group was made up of London Transport, Council, Transdev (Operator), Tarmac (Civil Engineering Contractor and A&G (tram builder). The PDG did a new feasibility study and produced an Environmental Statement. Transdev did new ridership forecasts and in fact came close to the values produced by LT. LT did the forecasts by modelling trips whilst Transdev counted the number of journeys being made at that time.

The government granted them the power to build in July 1994. The project then went out to tender. There were 4 good bids put in. If the PDG group lost then they recouped their development costs. These cost were added onto the costs of the other tenders. The winners were a consortium made up of: Amey McAlpine, Bombardier, Centre West

Bibliography

Ben Akiva, M. & Lerman, S. R. (1985), ***Discrete Choice Analysis, Theory and Application to Travel Demand***, The Massachusetts Institute of Technology, 1985.

Brady Shipman Martin (Planning Consultants), Kirk McClure Morton (Consulting Engineers), Fitzpatrick Associates (Economic Consultants), Colin Buchanan and Partners (Transportation Consultants) (Brady Shipman Martin et al., 1999), ***Strategic Planning Guidelines for the Greater Dublin Area.*** Dublin 1999.

Bratzel, S., ***Condition of success in sustainable urban transport policy – Policy change in 'relatively successful European cities.*** Transport Reviews, Vol. 19, No. 2, pp 177 – 190.

Breheny, M., ***Centrist, Decentrists and Compromisers: Views on the Future of Urban Form.*** In "The Compact City: A Sustainable Urban Form?", E & FN Spon, Oxford, UK, 1996.

Central Statistics Office (CSO, 1991), ***Census 1991, Small Area Population Statistics***. Stationery Office, Dublin, 1991.

Central Statistics Office (CSO, 1996), ***Census 1991, Small Area Population Statistics.*** Stationery Office, Dublin, 1996

Central Statistics Office (CSO, 2000), ***Statistical Bulletin, September 2000.*** Vol. LXXV, No.3, Stationery Office, Dublin, 2000.

Carpenter, S. & Jones, P., ***Recent Advances in Travel Demand Analysis***, Gower, Aldershot, 1983.

Cervero, R. (1984), ***Light Rail Transit and Urban Development.*** Journal of the American Planning Association, Vol. 50, No. 2, Spring 1984 pp133 – 147.

Cervero, R. (1989), ***America's Suburban Centres: the land use transportation link.*** Unwin Hyman, Boston, USA 1989.

Cervero, R. (1994), ***Transit-based housing in California: evidence on ridership impacts.*** Transport Policy, Vol. 1, No. 3, pp 174 – 183.

Commission of the European Communities (CEC, 1990), ***Green Paper on the Urban Environment.*** Brussels, 1990.

Commission of the European Communities (CEC, 1994), ***Europe 2000+: Co-operatioin for European Communities.*** Luxembourg, 1994.

Commission of the European Communities (CEC, 1999), ***Sustainable Urban Development in the European Union: a framework for action.*** Luxembourg, 1999.

Denant-Boemont, L. & Mills, G., (Denant-Boemont et al, 1999), ***Urban Light Rail: Intermodal Competition or Coordination.*** Transport Reviews, Vol. 19, No. 3, pp 241 – 253, 1999.

Department of the Environment, Transport and the Regions (DETR, 1999), ***Planning Policy Guidance Note 12: Development Plans.*** December 1999.

Department of the Environment and Local Government (DoE, 1999), Press Releases. ***Dempsey's Planning Bill Introduces Major Reforms Including Planning Initiative On Affordable Housing*** - 25 August 1999.: http://www.environ.ie:80/press/planningbill.html

Department of Environment & Department of Transport (DoE & DoT, 1994), ***Planning Policy Guidance: Transport.*** PPG 13, March 1994.

Dickens, I, ***Transport Investment, Economic Development and Strategic Planning: The Example of Light Rail Transit.*** Planning Practice and Research, Vol. 7, No. 2, pp 9 – 12, Summer 1992.

Dublin Docklands Development Authority (1999), ***Grand Canal Docks Dublin, Draft Area Action Plan 1999***.

Dublin Transportation Initiative (DTI, 1994), ***Final Report.*** May 1994.

Dublin Transportation Office (DTO, 1996) Origin & Destination Matrices from Saturn files.

Dublin Transportation Office (DTO, 1998), ***Transportation Review & Short-Term Action Plan.*** September 1998.

Dublin Transportation Office (DTO, 2000a), ***A Platform for Change.*** September 2000.

Dublin Transportation Office (DTO, 2000b) Origin & Destination Matrices from Saturn files.

Dueker, K.J.& Bianco, M.J. , ***Effects of Light Rail in Portland: Implications for Transit-Oriented Development Design Concepts.*** Center for Urban Studies, College of Urban and Public Affairs, Portland State University, July 1998, Discussion Paper 97-7.

Eastern Region Development Organisation (ERDO, 1985), ***Eastern Region Settlement Strategy 2001.*** Dublin, ERDO 1985.

ECOTEC Research and Consulting Ltd (ECOTEC, 1993), ***Reducing Transport Emissions through Planning.*** HMSO, London, 1993.

Edwards, M. & Mackett, R. (1996), ***Developing new urban public transport systems***, Transport Policy, Vol:3, No:4, pp225-239. 1996.

European Commission, (EC, 1996) Directorate-General for Transport, ***The Citizens' Network, Fulfilling the potential of public transport in Europe.*** European Commission Green Paper. Brussels, 1996.

Fiesler, E, ***Neural Network Classification and Formalisation.*** Computer Standards & Interfaces, vol.16, no.3, pages 231—239, special issue on Neural Network Standards, J.Fulcher (editor). North-Holland. 1994.

Fiesler, E. et al. "Layer Based Neural Formalisation" in "Artificial Neural Networks II," Alexander I. & Taylor J.G. (editors), vol.1, pages 329—332. North Holland/Elsevier Science Publishers, Amsterdam, The Netherlands. 1992.

Fox, P. (1994), ***French Pioneer, Nantes Opens Northern Section of Line 2.*** Light Rail Review 6, Platform 5 Publishing Ltd, Sheffield, November 1994.

Fulford, C., ***The Compact City and the Market: The Case of Residential Development.*** In "The Compact City: A Sustainable Urban Form?", E & FN Spon, Oxford, UK, 1996.

Greater Manchester Passenger Transport Authority & Executive (GMPTE, 1996), ***Metrolink to Eccles via Salford Quays.*** GMPTE, 1996.

Hall, P. and Hass-Klau, C., ***Can Rail Save the City?: the impacts of rail rapid transit and pedestrianisation on British and German Cities.*** Gower, Aldershot, UK, 1985.

Hamilton Osborne King & Department of Geography, TCD (HOK, 1991), ***Office Survey.*** Hamilton Osborne King, Dublin.

Hamilton Osborne King & Department of Geography, TCD (HOK, 1992), ***Office Survey.*** Hamilton Osborne King, Dublin.

Hamilton Osborne King & Department of Geography, TCD (HOK, 1993), ***Office Survey.*** Hamilton Osborne King, Dublin.

Hamilton Osborne King & Department of Geography, TCD (HOK, 1994), ***Office Survey.*** Hamilton Osborne King, Dublin.

Hamilton Osborne King & Department of Geography, TCD (HOK, 1995), ***Office Survey.*** Hamilton Osborne King, Dublin.

Hamilton Osborne King & Department of Geography, TCD (HOK, 1996), ***Office Survey.*** Hamilton Osborne King, Dublin.

Hamilton Osborne King & Department of Geography, TCD (HOK, 1997), ***Office Survey.*** Hamilton Osborne King, Dublin.

Hamilton Osborne King & Department of Geography, TCD (HOK, 1998), ***Office Survey.*** Hamilton Osborne King, Dublin.

Hamilton Osborne King & Department of Geography, TCD (HOK, 1999), ***Office Survey.*** Hamilton Osborne King, Dublin.

Hamilton Osborne King & Department of Geography, TCD (HOK, 2000), ***Office Survey.*** Hamilton Osborne King, Dublin.

Haq, G., ***Towards Sustainable Transport Planning: A comparison between Britain and and The Netherlands.*** Avebury, Ashgate Publishing Company, Aldershot, UK, 1997.

Haq, G. and Bolhuis, M., ***Dutch Transport Policy: From Rhetoric to Reality.*** World Transport Policy, Vol. 4, No. 1, pp 4 – 8.

Hass-Klau, C. & Crampton, G. (Hass-Klau et al., 1998), ***Light Rail and Complementary Measures.*** A Report for the Department of Environment, Transport and the Regions. Environmental and transport planning, Brighton, 1998.

Henning, A., ***Sustainable mobility versus sustained mobility: a summary and some concluding remarks.*** World Transport Policy & Practice, Vol. 1, No. 2, 1995, pp 46 – 48.

Irish Times (IT, 11/11/98), ***AIB to make £20m profit on Ringsend land sale.*** Jack Fagan, Wednesday, November 1, 1998.

Irish Times (IT, 13/3/99), ***Emotions are mixed when it comes to car clamping.*** Joe Humphreys, Saturday, March 13, 1999.

Irish Times (IT, 2/8/00), ***Construction of new bridge across Liffey at Docklands a strategic necessity for city.*** Frank McDonald, Wednesday, August 2, 2000.

Irish Times (IT, 29/8/00), ***Court sides with Minster on benefits of social housing.*** Tim O'Brien, Tuesday, August 29, 2000.

Irish Times (IT, 2/11/00), ***Planner raise transport issue.*** Thursday, November 2, 2000.

Irish Times (IT, 4/12/00), ***Row escalates over Wicklow growth plan.*** Tim O'Brien, Monday, December 4, 2000.

Irish Times (IT, 13/12/00), ***Docklands plan to point way ahead for next phase of development.*** Frank McDonald, Wednesday, December 13, 2000.

Irish Times (IT, 5/1/01), ***New authority will oversee greater Dublin area.*** Frank McDonald, Friday, January 5, 2001.

Irish Times (IT, 11/1/01a) ***Greater Dublin area authority called for.*** Thursday, January 11, 2001.

Irish Times (IT, 11/1/01b) ***Plans for Wicklow, Meath and Kildare threatened.*** Tim O'Brien, Thursday, January 11, 2001.

Irish Times (IT, 11/1/01c) ***An Bord Pleanala, Decisions to Grant Permission.*** Thursday, January 11, 2001.

Irish Times (IT, 2/2/01), ***Increase in Dublin parking charges strongly criticised.*** Anne Byrne, Friday, February 2, 2001.

Irish Times (IT, 2/3/01), ***City to get five new bus corridors.*** Frank McDonald, Friday, March 2, 2001.

Irish Times (IT, 4/7/01), ***Sideroads.*** Wednesday, July 4, 2001.

Jane's Urban Transport Systems (Jane's, 1997), Jane's Publishing Company Ltd, London, 1996-1997 ed.

Jane's Urban Transport Systems (Jane's, 1998), Jane's Publishing Company Ltd, London, 1997-1998 ed..

Jane's Urban Transport Systems (Jane's, 2000), Jane's Publishing Company Ltd, London, 1999/00 ed..

Law, C. & Grime, E., ***Salford Quays 1: the context.*** In Urban Waterside Regeneration: problems and prospects. Ellis Horwood, London, 1993.

Lemmers, L., ***How Amsterdam plans to reduce car traffic.*** World Transport Policy & Practice, Vol. 1, No. 1, 1995, pp 25 – 28.

Local Government (Planning and Development) Act (LGA), 1999, http://www.environ.ie/pdf/planbill.pdf

LONDON DOCKLANDS DEVELOPMENT CORPORATION (1997), ***Starting From Scratch, The Development of Transport in London Docklands.*** LDDC, London 1997.

Maren, A., Harston, C. & Pap, R. (Maren et al., 1990), ***Handbook of Neural Computing Applications***, Academic Press, San Diego, 1990.

Martin, D., ***Geographic Information Systems, Socioeconomic applications.*** Routledge, London 1996.

Mackett, R. & Edwards, M. (1996), ***Guidelines for planning a new urban public transport system.*** Proceedings Institution of Civil Engineers, 1996, Vol 117, August, pp 193 – 201.

MacLaran, A., ***Dublin, The Shaping of a Capital.*** Belhaven Press, London, 1993 .

Modern Railways (1988), ***New Railways for London 2, Modern Railways Special.*** Ian Allan Publishing, Hersham, UK, 1998.

New Civil Engineer (NCE, 1998), ***London's Docklands***, London, 19 February 1999.

New Civil Engineer (NCE, 1999), ***Delivering the JLE***. NCE Jubilee Line Supplement, London, October 1999.

Newman, P. and Thornley, A., ***Urban Planning in Europe, International competition, national systems and planning projects.*** Routledge, London, 1996.

O'Flaherty, C., & Coleman, A., ***Transport Planning and Traffic Engineering.*** Arnold, London, 1997.

Ortuzar, J. & Willumsen, L., ***Modelling Transport.*** John Wiley & Sons Ltd., Chichester, England, 1994.

Pearce, A., Jolly, S., Hardy, B. (Pearce et al., 1994), ***Docklands Light Rail, Official Handbook.*** Capital Transport Publishing, Middlesex, 1994.

Perry, S., ***Mass Transit as a Policy Instrument***, in 'Transport in Dublin, Policy and Practice', An Tasice, Dublin 1989.

Reggiani, A. and Tritapepe, T. (1998), ***Neural Networks and Logit Models Applied to Commuters' Mobility in the Metropolitan Area of Milan***, in 'Neural Networks in Transport Applications', Ashgate Publishing, Aldershot, England, 1998.

Ridley, T., ***What is a Successful Urban Transit Project?*** Fifth Professor Chin Memorial Lecture, Kuala Lumpar, 1995.

Rogers, J., ***Object-Oriented Neural Networks in C++.*** Academic Press, San Diego. 1997.

Rosenbaum, E., Van Leeuwen, M. and Manshanden, W. (Rosenbaum et al., 1998), ***Structural change in the transport sector: a review of spatial and fiscal policy in The Netherlands and the UK.*** Transport Reviews, Vol. 18, No. 1, pp 57 – 82.

Royal Commission on Environmental Pollution (RCEP, 1995), ***Transport and the Environment***. Eighteenth Report, Oxford University Press 1995.

Salford City Council, ***Salford Quays, Development Strategy Review.*** Salford City Council, August 1988.

Seaton, J.J., ***Pedestrian priority planning principles.*** World Transport Policy & Practice, Vol. 6, No. 2, 2000, pp 32 – 39.

Shepeard, Epstein and Hunter (Shepeard et al, 1990), ***Salford Quays, The Development Plan for Salford Docks.*** City of Salford, 1990 (first published 1985).

Shmueli, D., Salomon, I. & Shefer, D. (Shmueli et al, 1998), ***Neural Network Analysis of Travel Behaviour***, in 'Neural Networks in Transport Applications', Ashgate Publishing, Aldershot, England, 1998.

Slattery, P., ***Light Rail Transit (LRT) as a Land Use "Vehicle".*** MPhil in Environmental Planning, University of Reading, Department of Land Management and Development School of Planning Studies. September 1995.

Steers Davies Gleave (SDG, 1994), ***Dublin Transportation Initiative, Final Report.*** Stationery Office, Dublin, 1994.

Steers Davies Gleave (SDG, 1995), ***Dublin Transportation Initiative, Technical Volume 1, Transport Modelling in Phase 2.*** Stationery Office, Dublin, 1995.

Still, B., May, T. and Bristow, A. (Still et al., 1998), ***Transport Impacts on Land Use: Potential Methods and their Relevance to Strategic Planning.***

Thom's Dublin & County Street Directory. (Thom's, 2000), Dublin: Thom 2000.

Transport Consultative Commission (1980), ***Passenger Transport Services in the Dublin Area: Report of the Transport Consultative Commission to the Minister for Transport, March 1980.*** Dublin, Stationery Office, 1980.

TRI-MET (1996), ***Planning and Design for Transit Handbook, Guidelines for implementing transit supportive development.*** Tri-County Metropolitan Transportation District of Oregon, USA, January 1996.

World Commission on Environment and Development (WCED, 1987), ***Our Common Future.*** Oxford University Press, 1987.

Wright, M. (1967), ***The Dublin Region, Advisory Regional Plan and Final Report 1967.*** Dublin, Stationery Office, 1967.

Appendix 1

Pilot Study Questionnaire

****

Everybody who returns a fully completed questionnaire, reaching me not later than Friday 10th March will be entered in a prize draw for a £50 voucher for HMV!

Thursday, February 21st, 2000
Dear Sir or Madam:

Questionnaire to provide Data for Transport Study

I am currently undertaking research towards a Ph.D. in the Department of Civil, Structural & Environmental Engineering under the supervision of Professor S.H. Perry. The aim of my research is to establish the benefit of extending quality public transport into the South Docklands redevelopment area (Grand Canal Dock, Ringsend & Irishtown). In order to do this I am developing a new type of transport model.

A person travelling to work must choose a particular means of transport for his or her journey. This choice may depend on quite a large number of factors, and it is the way in which people make their choices that I am seeking to model. In order to collect the necessary information a questionnaire-based survey is being prepared for the South Docklands area.

To further my work, I am developing a test model, which will look at the transport choices made by people travelling into Trinity College. I would be grateful if you could take the time to fill in the questions and return it to me. It is hoped that any problems with the model can be ironed out in this test run before I undertake the larger survey outside College.

Your support is much appreciated and if you have any queries please do not hesitate to contact me at qrheaney@tcd.ie. Remember you have an opportunity to collect a £50 voucher!!

Yours sincerely,
Quentin Heaney

Please do one of the following:

- ***Copy questionnaire into the body of an e-mail and mail completed version back to me at qrheaney@tcd.ie***
- ***Print questionnaire and return completed version back to me at***
  Quentin Heaney
  Department of Civil, Structural and Environmental Engineering,
  Museum Building,
  College

Trinity College Transport Survey

Please fill out the answers to the following questions with reference to your trips to work for last week.

Please state the date of the Monday of this week for reference purposes:.....

Please indicate with an X the principal method that you used to travel to work each day last week?

Monday

Car (as driver):.....
Car (as passenger):.....
Bus:.....
DART/suburban rail:.....
Bicycle:.....
Walk:.....
Other:.....

Tuesday

Car (as driver):.....
Car (as passenger):.....
Bus:.....
DART/suburban rail:.....
Bicycle:.....
Walk:.....
Other:.....

Wednesday

Car (as driver):.....
Car (as passenger):.....
Bus:.....
DART/suburban rail:.....
Bicycle:.....
Walk:.....
Other:.....

Thursday

Car (as driver):.....
Car (as passenger):.....
Bus:.....
DART/suburban rail:.....
Bicycle:.....
Walk:.....
Other:.....

Friday

Car (as driver):.....
Car (as passenger):.....
Bus:.....
DART/suburban rail:.....
Bicycle:.....
Walk:.....
Other:.....

To travel by bus or rail, what do you need to do to reach the stop/station? You may choose more than option.

Bus: (walk less than 5 minutes to stop):.....
Bus: (walk more than 5 minutes to stop):.....
Bus: (cycle to bus stop):.....
Bus: (drive to bus stop):.....
Bus: (lift to bus stop):.....

DART/suburban rail (walk less than 5 minutes to station):.....
DART/suburban rail (walk more than 5 minutes to station):.....
DART/suburban rail (bus to station):.....
DART/suburban rail (cycle to station):.....
DART/suburban rail (drive to station):.....
DART/suburban rail (lift to station):.....

If you didn't travel by car to work, and you have a driving license, was there a car available in your household that you could have taken? Y/N

Mon.....
Tues.....
Wed.....
Thur.....
Fri.....

If your travelled to work as a car driver, where did you park you car?

Work:.....
Free:.....
Pay:.....

Parking types: 'Work' means that you parked in a work provided space with no cost to yourself, 'Free' means that you parked in a public place for no cost, and 'Pay' refers to parking either on or off-street where you personally have to pay.

Please estimate the travel time for each type of transport, which you could possibly use, peak and off-peak, from home to work. For each type of transport quote the actual door-to-door time including, walking and waiting times.

Peak (0730--9300)

Car:.....
Bus:.....
DART:.....
Bicycle:.....
Walk:.....

Off-peak

Car:.....
Bus:.....
DART:.....
Bicycle:.....
Walk:.....

If any of the days were wet, while you were travelling to work, please place a "W" after the relevant day. If your travel time changed from normal please state.

Mon.....
Tues.....
Wed.....
Thur.....
Fri.....

What time did you arrive at work each day last week?

Mon.....
Tues.....
Wed.....
Thur.....
Fri.....

What is the distance in miles from home to work?

.....Miles

Or if you prefer kilometres: .....Kilometers

Indicate (mark with an 'x') your preferred means of travel if all options were viable.

Car .....
Bus.....
DART.....
Bicycle.....
Walk.....

Marital Status (mark with an 'x'):

Married.....
Separated.....
Single .....
Widowed.....

Age (mark with an 'x')

Less than 25.....
25 -- 34.....
35 -- 44.....
45 -- 54.....
55 -- 64.....
Greater than 65.....

Number of children in the household:

Under 4 years of age .....
Primary School age .....
Secondary School age.....

Please give your postal district, for example Dublin 14 or Co. Meath:

.....

Please include any comments that you consider might be useful

Appendix 2

Array Shuffling

An array 'index' of 'int' values is created and initialised with values from 0 to the number of patterns read in. This array is then shuffled using the following piece of code:

```
srand( (unsigned)time( NULL ) ),
for (i = 0, i < m_number_of_patterns, i++)
        {
                int y = rand() % m_number_of_patterns,
                int temp = index[i],
                index[i] = index[y],
                index[y] = temp,
        }
```

The function 'rand' (in the code above) will produce the same set of 'random' numbers for each run of the program unless it is given a different starting point. The first line of the code above 'seeds' the random generator with the current time so that a different sequence of numbers is produced for each model run. The 'for' loop then enables the program to step through the array stopping at each location and swapping that value with another randomly chosen member of the array.

Appendix 3

Docklands Transport Survey Letter

May, 2000

Dear Sir/Madam,

T.C.D. – Docklands Transport Survey

I am currently undertaking research in Trinity College, under the general direction of Professor Simon Perry, on how new and improved public transport services can be best fitted to the changing needs of your area. A mathematical model is being developed that models the trip patterns of your area in the ***morning peak***. Detailed information of the trips made in the area during the morning peak is required and all of the information being sought in the questionnaire is essential for the success of this project. Thus I would be most grateful if you could fill in the attached survey – IT WILL ONLY TAKE 10 MINUTES! – AND THERE IS A PRIZE DRAW!

Please fill in ***all*** the questions on the questionnaire and return using the Business Reply envelope provided – ***no stamp is required.*** If you wish to be entered in the ***Prize Draw*** please include your name and full address on the back of the fully completed questionnaire and return by Friday 9th June.

The information you provide ***will enable me to make recommendations for improved and/or new public transport routes in your area.*** If you have any further comments that you think I might find useful, please include them.

If you have any queries please do not hesitate to contact me at the above address, or if you have e-mail, at: docklandssurvey@hotmail.com

Yours faithfully,

Quentin Heaney

Appendix 4

Docklands Transport Survey Questionnaire

Department of Civil, Structural & Environmental Engineering

Trinity College Dublin – Docklands Transport Survey

Please fill out the answers to the following questions with reference to your trips to work for last week.

Week beginning Monday [redacted]/[redacted]/2000 (for reference purposes)

1. Please indicate with an "X" the **principal method that you used to travel to work** each day last week.

	Car (as driver)	*Car (as passenger)*	*Bus*	*DART*	*Cycle*	*Walk*	*Worked from home*	*Other, (please state)*
Mon.								
Tues.								
Wed.								
Thurs.								
Fri.								

2. If you didn't travel by car to work, was there a car available in your household that you could have taken?

	Mon	*Tues*	*Wed*	*Thurs*	*Fri*
Yes/No →					

3. Do you have a car parking space available to you at work and if so please indicate which type?

Free at work	*Free in public place near work*	*Daily cash payment required*

4. For you to travel by bus would it be necessary for you to use more than one bus?

Yes	*No*

5. How would you usually reach the bus stop?

Car	*Cycle*	*Walk*

6. How would you usually reach the DART station?

Car	*Bus*	*Cycle*	*Walk*

7. If you travel by public transport, do you use a weekly or monthly travel pass?

Yes	*No*

8. What cash price would you have to pay for a trip to work by public transport without a travel pass?

£

9. If you normally travel by car, please indicate if one or more of the following factors means that you ***have*** to travel by car.

Need car during work day	*Need car for leisure activities after work*	*Need car for school/child minder run to/from work*	*Other: Please State.*

10. What is the distance in miles from home to work?

(Or if you prefer kilometres)

	Miles
	Kilometres

11. So that I can locate your trip on a map please fill in the following:

Street name of you **place of residence**:

Street	
Town	

Street name of your **place of work**:

Street	
Town	

If your street is quite long, could you please give me an indication of which end of it you are referring to.

12. What time of day do you usually start work?

Before 07:30	*07:30 – 08:29*	*08:30 – 09:29*	*After 09:30*

13. Would your start time change if traffic problems were not an issue, and if so to what?

Before 07:30	*07:30 – 08:29*	*08:30 – 09:29*	*After 09:30*

14. Male/Female:

Male	*Female*

15. Age:

Less than 25	*25 – 34*	*35 – 44*	*45 – 54*	*55 – 65*	*Greater than 65*

16. Please indicate which description best describes your current employment status.

Employed	*Seeking 1st Job*	*Unemployed*	*Student*	*Home Duties*	*Retired*	*Unable to Work*	*Other*

17. If employed please state your job description:

18. Besides yourself, please state the ***number of other members*** of your household in each of the following categories.

Under 4	*Primary school age*	*Secondary school age*	*Adults*

19. Besides yourself, please state the ***number of other members*** of your household using each method to travel each morning.

Car (as driver)	*Car (as passenger)*	*Bus*	*DART*	*Bicycle*	*Walk*	*Stay at home*	*Other*

20. How long have you been in your current place of residence?

Less than 1 year	*1 – 2 years*	*3 – 5 years*	*6 – 10 years*	*More than 10 years*

21. How long have you been in your current place of employment?

Less than 1 year	*1 – 2 years*	*3 – 5 years*	*6 – 10 years*	*More than 10 years*

22. Could you please select which income bracket you are in?

Less than £10,000	*£10,000 – £14,999*	*£15,000 – £19,999*	*£20,000 – £24,999*	*£25,000 – £29,999*	*£30,000 – £50,000*	*Greater than £50,000*

23. In an ideal situation please rank from 1 to 6 how you would like to travel to work every day?

1 = preferred

→ 6 = least preferred

Car	*LUAS*	*Bus*	*DART / Suburban rail*	*Walk*	*Bicycle*

24. Please rank how important the following factors are in determining your choice of transport method.

	Security	*Health*	*Comfort*	*Guaranteed journey time*	*Time*	*Other (please state)*
1 → 6						

25. Do you require level access to be able to use public transport? (that is, no steps involved)

Yes	*No*

26. Please estimate your travel time for the principal transport methods you could possibly use (peak and off-peak), from home to work in the morning. It would assist greatly if you could estimate travel times for modes that are possible, even though you may never use them.

For each type of transport quote the ***actual door-to-door time*** including, walking and waiting times. For example the total time of a DART trip for somebody **driving 10 minutes** to the station, **waiting 5 minutes**, travelling **20 minutes by DART** and then **walking 10 minutes** to their final destination is **45 minutes door-to-door**.

	Car	*DART*	*Bus*	*Bicycle*	*Walk*	*Other* *(please state)*
Peak (07:30 – 09:30)						
Off-peak						

If you wish to be entered in the ***Prize Draw*** please include your name and full address here:

Prizes include a ***£50 cash prize*** and a number of runners up prizes.

Please include any comments that you consider might be useful:

The information provided by you will be used solely for the purpose stated in the included letter and will not be passed on to any 3rd party.

Appendix 5

Neural Network Configuration Runs

Middle	*Test No*	*Train*	*Predict*	*Accuracy*	*Average*	*SD*
19	1	98%	65%	1.11		
	2	98%	65%	0.94		
	3	98%	65%	0.86		
	4	98%	66%	0.91		
	5	98%	65%	1.09	0.98	0.11
16	1	98%	68%	0.88		
	2	98%	68%	0.73		
	3	98%	68%	0.96		
	4	98%	66%	0.96		
	5	98%	66%	0.68	0.84	0.13
13	1	97%	65%	0.68		
	2	97%	64%	1.21		
	3	97%	65%	1.60		
	4	97%	67%	1.26		
	5	97%	67%	1.29	1.21	0.33
9	1	97%	63%	1.33		
	2	97%	64%	0.72		
	3	97%	66%	1.59		
	4	97%	63%	1.50		
	5	98%	68%	0.95	1.22	0.37

Test Runs for different numbers of middle layers

Appendix 6

Personal Characteristics Matrix Formulation

CSO Data (1991 & 1996) is available for the composition of private households by various categories in terms of numbers of households and people. The total number of children in private households in Pembroke East A is given as 1,729 children. The CSO definition of a child is a person who lives with their parents, has never been married and is of any age. For the purposes of this work it is necessary to redefine a child as of school or pre-school age. This is taken to be anybody aged 17 or under and half of the 18 year olds.

The first two rows of Table 1 show the male and female population of Pembroke East A classified by age. A child is taken to be all of the 0 – 15 category and a proportion of the 15 – 24 category relating to 15, 16, 17 and half of the 18 year olds. Adults are assumed to be the rest of the 15 – 24 category and above. This gives the following:

- Total adults: 3,224 (Male: 1,493, Female: 1,731),
- Children: 1,125.

	0 - 15	*15 - 24*	*25 - 34*	*35 - 44*	*45 - 54*	*55 - 64*	*65 +*	*Total*
Male	422	381	379	269	201	180	218	2,050
Female	432	394	415	298	201	215	344	2,299
Male adult	0	246	379	269	201	180	218	1,493
Female adult	0	258	415	298	201	215	344	1,731
Children	854	271						1,125

Table 1: Pembroke East A Population Age Classification. (Source: CSO, 1996)

Table 2 shows the composition of private households by various categories in terms of numbers of households and people. It is possible to develop this into the number of adults and children in each category. The CSO numbers refer to 1,729 children whilst it has now been defined that there are 1,125 children. This means that 65.1% of the CSO children will be placed in the children row whilst the rest will be placed in the adults row.

	1 - P	*Couple*	*C + Ch*	*F + Ch*	*M + Ch*	*C + O*	*C + Ch + O*	*F + Ch + O*	*M + Ch + O*	*2 family units*	*non-family hhlds + relations*	*2+ p not related*	*Total*
Hlds	**383**	**174**	**447**	**17**	**185**	**26**	**63**	**7**	**32**	**12**	**81**	**81**	**1,508**
People	**383**	**348**	**2,037**	**46**	**503**	**87**	**343**	**27**	**125**	**67**	**188**	**195**	**4,349**
Adults	383	348	1,293	27	296	87	251	19	90	47	188	195	3,224
Children	0	0	744	19	207	0	92	8	35	20	0	0	1,125
YA YC			*1,293*	19	204		*251*	*19*	*90*	*47*			1,923
YA NC		*348*				*87*					*188*	*195*	818
NA YC				8	92								100
NA NC	*383*												383

Table 2: Composition of Private Household (Source for fields in bold: CSO, 1996)

Legend:

P: Person, CH: Children, M: Mother, YA: Other Adults in house YC: Children in house

C: Couple, F: Father, O: Other adults, NA: No other Adults in house NC: No Children in house

The column titled *'C +Ch'* has 2,037 people living in 447 households. As this refers to a couple and children, twice 447 will give the number of parents and the rest will be CSO children (1,143 persons). 65.1% of 1,143 is placed in the children's row (744 persons). The difference between the total number of people (2,037) and the 744 children gives the number of adults.

The distribution of adults and children must be such that the totals add up to the total numbers of adults and children. Two additional pieces of data are required to distribute the numbers of adults and children:

- Number of adults in 2 family unit households, and
- Number of other adults in households.

The numbers of adults in 2 family unit households was assumed to be 3. To fulfill the total requirement for adults and children the average number of other adults in households was determined to be 1.21. The next step is to apportion the adults into their sub-categories in Table 2. For purposes of clarity the following will be used to represent the categories:

- YA YC: Person living with both other adults and children,
- YA NC: Person living with other adults but no children,
- NA YC: Person living on own with children,
- NA NC: Person living on own.

It is possible to logically place the majority of adults into their appropriate category. Those for which this is possible are shown in italics in Table 2. The columns where the uncertainty occurs is for the single parent with children as some of these households will have an adult child. CSO data shows that 50% of all households with children have at least one adult child. This means that 50% of the single parent households are

placed in the YA YC category and 50% in the NA YC category. The adults are therefore split between the two categories accordingly.

The next step is to transfer the data from Table 2 into Table 3 where the data is further subdivided into male and female. The totals can be directly transferred from Table 2 to Table 3. The number of males and females living alone without children (NA NC) is given in CSO data and so is filled in. The data in Table 3 that is shown in bold and italics is data that has been filled in directly from CSO data or Table 2 as described above.

The remaining data must be proportioned between male and female such that it satisfies the individual category totals and the overall total. It was assumed that the same male female ratio would be applied to both. A ratio of 51.45%:48.55% male:female was found to satisfy both criteria and the remaining data was filled in.

Adults	Y		Y		N		N			
Children	Y		N		Y		N		Total	Total
Male or Female	M	F	M	F	M	F	M	F	M	F
Number Adults	934	989	397	421	8	92	***154***	***229***	***1,493***	***1,731***
Total		***1,923***		***818***		***100***		***383***		***3,224***

Table 3: Person Matrix

The matrix in Table 3 needs to be further subdivided for age categories. Again CSO data provides detailed information for category NA NC. This age data is filled into the table in bold and italics. The totals for each category are filled in at the bottom of Table 4. Table 4 shows the total numbers of males and females in each age category. The data in the last column of Table 4 was subtracted from this data leaving an age profile, which corresponds to the remaining categories. Ideally an individually unique age profile would be applied to each of the remaining categories but in the absence of more detailed data this average age profile was distributed over each remaining category.

This complete person matrix (Table 4) must now be adapted so that it represents the person characteristics of those people that will make a trip to work in the morning. To do this it is necessary to remove the following categories of people:

- Retired,
- Home duties,
- Not working,
- Unemployed.

Adults	Y		Y		N		N	
Children	Y		N		Y		N	
Male or Female	M	F	M	F	M	F	M	F
< 25	169	168	72	71	1	16	***4***	***3***
25 - 34	249	252	106	107	2	23	***22***	***32***
35 - 44	172	176	73	75	2	16	***22***	***31***
45 - 54	126	124	54	53	1	12	***20***	***13***
55 - 64	109	117	46	50	1	11	***23***	***37***
> 65	109	152	46	65	1	14	***63***	***113***
Total	***934***	***989***	***397***	***421***	***8***	***92***	***154***	***229***

Table 4: Person Matrix with Age Categories

The census (CSO, 1996) gives data on the percentage of people in these categories for each ward. The percentages for Pembroke East A are as follows:

- Retired → Male: 14.05%, Female: 9.53%,
- Home duties → Male: 0.43%, Female: 31.82%,
- Not working → Male: 6.39%, Female: 5.14%,
- Unemployed → Male: 18.73%, Female: 10.50%.

It is assumed that all of the retired people are contained in the over 65 age category. For the two categories 'home duties' and 'not working' the rest of the over 65 category is removed first and then the other age categories are reduced proportionally. The unemployed figures have changed considerably since 1996. It is decided that unemployment figures for the whole of Dublin in 2000 will be more accurate than those for the ward in 1996. These figures are (CSO, 2000):

- Male: 4.8%
- Female 4.6%

The unemployed people are removed proportionally from the rest of the age groupings. Table 5 shows the morning work origin matrix of personal characteristics. The total number of origins is as follows:

- Male: 1,104
- Female: 846

Adults	Y		Y		N		N	
Children	Y		N		Y		N	
Male or Female	M	F	M	F	M	F	M	F
< 25	146	102	62	43	1	10	4	2
25 - 34	216	154	92	65	2	14	19	20
35 - 44	149	107	63	46	2	10	19	19
45 - 54	109	76	47	32	1	7	17	8
55 - 64	94	71	40	30	1	7	20	23
> 65	0	0	0	0	0	0	0	0
Total	***714***	***510***	***304***	***216***	***7***	***48***	***79***	***72***

Table 5: Origin Personal Characteristics Matrix

Appendix 7

Trips Generated from each Residential Location

To calculate the total number of people in the ward the occupancy figures from the 1996 Census were used. Occupancy figures are provided individually for apartments and houses for each ward. The occupancy rates in Pembroke East A were:

- House: 2.98
- Apartment: 2.62

The number of residents in Pembroke East A calculated for 2000 is 4,698 people. Using the figures from Table 1, Appendix 6, it can be shown that 25.87% of people in the ward in 1996 are children. The proportion of children living in apartments is significantly less than that living in houses. Since it is three apartment complexes that have been added since 1996 it is necessary to apply the percentage to the total population minus the new apartments. This gives a total of 4,279 people with a target of 1,107 children in 1996 figures.

The survey data (section 5.5) gives us figures for the difference between the proportion of children living in the different house types. The proportions of adults are as follows:

- House: 70%
- Apartment: 94%

An adjustment is then applied to achieve the target total of children in 1996 figures. It is necessary to reduce the proportion of adults by three percentage points for both so that the total number of children is achieved. Table 6.2 shows the numbers of adults and children calculated for each residential location. The numbers of adults and children in 2000 figures is derived to be:

- Adults: 3,558
- Children: 1,140

Table 5.4 provides data to proportion the adults data into male and female numbers. Table 6.2 shows the numbers of males and females for each residential location and the total numbers are:

- Male: 1,646
- Female: 1,912

As in appendix 5 the four categories of non-work trip makers are removed. It is important to note that all of the members of the retirement home are classified as retired and so are removed within this calculation. The total number of origins is given as follows:

- Male: 1,216 origins
- Female: 931 origins